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What do you mean by '(un-)suitable'? Analysing the diversity of social acceptance towards the deployment of renewable energies in different landscapes

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ABSTRACT

Local energy transitions are shaped by diverse stakeholder perspectives on land use, reflecting competing values, knowledge systems, and political views. This study applies the landscape services framework to systematically assess renewable energy (RE) suitability across different landscapes, capturing both ecological and socio-cultural dimensions. Through stakeholder surveys in two German regions and statistical comparative analysis, we reveal how suitability perceptions vary significantly: (1) between stakeholder groups (e.g. conservationists vs. developers), (2) across regions (industrial vs. ecological-cultural contexts), and (3) even within groups sharing similar objectives. Key findings show strong preference for RE development in industrial and agricultural zones ('acceptance corridors') and opposition in ecologically sensitive areas, though with notable regional exceptions. The landscape services approach proves effective in mapping these conflicts and consensus areas, providing actionable insights for spatially sensitive RE planning. Our results underscore the need to complement technical siting criteria with structured assessments of social landscape values to enable just and locally accepted energy transitions.

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Renewable energy siting; energy transition; landscape services; suitability

1. Introduction

Wind and solar energy plants have been expanding in Germany for over two and a half decades. Although these small power plants are socio-politically accepted (Wüstenhagen et al., 2007), major conflicts repeatedly arise during local project development in municipalities, leading to long delays or even project cancellations (Batel & Devine-Wright, 2015; Devine-Wright & Batel, 2013; Reusswig et al., 2016; Toke, 2005). The prevailing approach to renewable energy (RE) planning and siting in Germany is characterised by a top-down approach aimed at identifying potential sites with the lowest risk of conflict and the highest likelihood of realisation for RE deployment, in the sense that there are no other spatially significant land uses that conflict with the use of RE (Bruns et al., 2016). The

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regulation of prospective locations through the instrument of planning law, manifested in the form of an exclusion of usage, is designated as 'negative control' (Bruns et al., 2016). By establishing expansion targets at the national or state level, the government sets the framework within which subordinate planning authorities operate and prepare regional plans for the designation of RE sites (Wiehe et al., 2020). The process entails a systematic assessment of various legal and factual exclusion criteria pertaining to RE to gradually narrow down the search space for potential sites. Ultimately, the objective is to arrive at areas with either no or minimal legal impediments or factual barriers, such as water bodies, relief, or existing development (Mostegl et al., 2017). In the case of wind energy, these areas can then be designated as priority areas for the development of wind turbines in regional plans, whereas ground-mounted photovoltaic systems are ultimately regulated by land-use plans issued by local municipalities.

The application of this approach on a national scale for Germany has shown that there are sufficient areas available to meet the national targets for the deployment of wind (Bons et al., 2022) and solar energy technologies (BMVI, 2015; UBA, 2022). However, despite the availability of sufficient areas for wind and solar energy in Germany from both a technical-economic and planning law perspective (Wiehe et al., 2020), local acceptance problems for the expansion continue to exist (Baur et al., 2022; Bertsch et al., 2016). This suggests that the top-down approach, which focuses exclusively on broader technical-economic and legal criteria for identifying suitable locations for RE may be insufficient for identifying socially acceptable sites at the local level. It appears that there is a discrepancy between the technical, economic and legal categorisation of landscapes and the local perception of their suitability for RE. This approach does not consider the diverse local social contexts, including conflicting opinions on land suitability by different stakeholders, which are not reflected in standardised cartographic visualisations and legal constraints.

The disparity in acceptance of energy infrastructure between the national and local level is commonly referred to as the 'social gap' in research (Bell et al., 2005, 2013). Recent social energy research has thus analysed factors that significantly influence the local acceptance of RE (Devine-Wright, 2005; Enserink et al., 2022; Wüstenhagen et al., 2007) to gain a better understanding of the partial rejection of energy infrastructure at the local level. These factors include socio-economic, ecological, procedural, landscape-visual factors (Petrova, 2016; Rand & Hoen, 2017) and psychological factors (Huijts et al., 2012; Perlaviciute et al., 2018). Integrating these acceptance factors into planning procedures can be challenging and is rarely done throughout the entire siting decision process (Spyridonidou & Vagiona, 2020; Zaunbrecher & Ziefle, 2016). However, translating theoretical knowledge into practice is crucial for a strong and targeted expansion of RE, consistent with national and international climate strategies, to gain social acceptance at all spatial scales. In addition to the commonly discussed ecological, economic, and legal factors, it is therefore essential to integrate social factors even more strongly into the development of methods and planning practices for renewable energies.

As it is generally assumed that the installation of RE facilities will lead to undesirable changes in the landscape, consequently participatory processes are frequently initiated with the aim of mitigating these changes and securing local acceptance for the installation of such facilities (Batel, 2020). Local opposition to RE projects is thus often merely seen as a barrier that needs to be overcome (Aitken, 2010) and can be strategically managed by building consensus and public support for the energy transition (Krick, 2018), rather than as something constructive that can foster a deeper understanding of local contexts and the contingent suitability and values of different landscapes for the local population. As a result of these assumptions, processes of local stakeholder engagement often only take the form of the 'decide-announce-defend' (DAD) model (Komendantova & Battaglini, 2016), where the outcomes of planning processes are simply communicated to the public and then defended against opposition. This approach adopts a highly normative top-down perspective on the planning process for RE, whereby local acceptance is perceived as a means of legitimising or justifying the project (Rau et al., 2012). In order to gain a deeper insight into the controversies surrounding energy infrastructure, it is essential to adopt a more comprehensive approach that encompasses not only the opposition but also the wider range of stakeholders involved (Van De Grift & Cuppen, 2022). By analysing the assumptions and values that underpin their positions, it becomes possible to develop a more nuanced understanding of the issues at stake.

To determine appropriate and locally accepted sites for RE, it is therefore essential to integrate local and stakeholder-specific assessments of landscape suitability into spatial modelling. This is particularly important in cases where numerous stakeholders are involved in spatial planning processes at various levels, as there may be diverse perspectives and expectations of the landscape (Müller et al., 2020). To guarantee the successful implementation of renewable energies in a variety of local contexts, it is essential that participatory planning processes allow for a range of opinions on landscapes and technologies. Furthermore, these processes must be initiated at an early stage of the siting process (Spyridonidou & Vagiona, 2020). This allows for adaptability during the energy transition while maintaining various interpretations of landscapes. Presenting differing viewpoints on landscape suitability can challenge entrenched positions and lead to more flexible interpretations of sites. This, in turn, could improve the overall social acceptance of renewable energies.

An approach that reflects local values and norms of key stakeholders in the energy transition is therefore needed to better assess the spatial potential for further expansion and the acceptance of sites for RE (Zaunbrecher & Ziefle, 2016). Research must focus on social discourses regarding the acceptability of the growing mechanisation of landscapes (Bosch et al., 2020), the environmental and social benefits of landscapes for people, and thus local and contextual assessment of (un-)suitability of specific landscapes for renewable energies (Bidwell, 2013; Schlenker & Bosch, 2024).

This paper aims to address the complexities of different suitability perspectives inherent in the field of RE siting by adopting the concept of landscape services, a concept that describes landscapes as spatial human-ecological systems, thus attempting to capture the different functions that a landscape can provide to, and in turn be valued by, humans (Termorshuizen & Opdam, 2009). Through this conceptual lens we aim to operationalise and quantify stakeholder perspectives on the suitability of different landscapes. By using the categories of landscape services, we seek to explore how diverse stakeholders perceive the suitability of different landscapes for RE and contribute to the development of a more inclusive and locally adapted framework for RE siting. To achieve this, the following research questions guide the study:

(1) How can stakeholder-specific energy landscapes be operationalised and quantified in terms of landscape suitability for renewable energy?
(2) To what extent are regional, group or context-specific assessments of landscape suitability for renewable energy observed?
(3) How can these regional stakeholder perspectives contribute to existing approaches to renewable energy siting?

To this end, a survey was conducted among RE stakeholders in two planning regions in Germany: Lausitz-Spreewald in the north-east and Ingolstadt in the south. The former is a historic energy region with a long history of lignite mining and a leader in RE installations, but faces structural challenges. In contrast, the latter is an economically strong region, yet a laggard regarding RE. Representatives from civil society, economy, politics, and interest groups were questioned via an online survey about the suitability of specific landscapes as sites for renewable energies. The present study focuses on the two RE technologies of wind and photovoltaic (PV) energy (defined here as ground-mounted systems), which are the subject of considerable public and scientific debate regarding siting decisions (Batel et al., 2015; Hindmarsh, 2014). Furthermore, these technologies are expected to expand significantly in the coming years to meet national and international climate targets (Krick, 2018; Reitz et al., 2022).

The following section presents a theoretical analysis of the conceptualisation of landscapes and their valuation, and how they relate to energy landscapes. Section 3 describes the methodology and data used for the study. Section 4 shows the results of the survey and their spatial visualisation. Section 5 discusses key findings and regional disparities in the assessment of the suitability of landscapes for renewable energies. The conclusion in section 6 offers recommendations for future research.

2. Theoretical background

The debate about RE siting is inextricably linked to the concept of landscapes. Due to their dispersed and decentralised spatial impacts (Nadaï & Van Der Horst, 2010) and their high visibility (Pasqualetti, 2000), RE infrastructure can be viewed as a reconfiguration of socio-technical relationships between energy and landscapes, thereby creating new energy landscapes (Bosch et al., 2020, Nadaï & Van Der Horst, 2010). The landscapes of Europe are the result of natural and cultural processes that have occurred over centuries. This has led to a variety of landscapes with distinct natural features and forms of human land use, and thus 'landscapes can be seen as the result of people's interactions with their environment' (Keller et al., 2019, p. 1).

The demand for landscape as a resource is increasing due to rapid technological advancements, economic growth, and urbanisation. Therefore, more material and immaterial demands are competing for its use (Grêt-Regamey et al., 2011). However, the term 'landscape' lacks a clear definition and its interpretation varies depending on the perspective and background (Arifi et al., 2017; Bastian et al., 2014). Leibenath and Gailing (2012) distinguish between four possible concepts of landscape: 1. as a physical space that describes a part of the earth's surface or a complex of ecosystems, 2. as a product of human-environment relationships and as a cultural landscape, 3. as a metaphorical description and 4. as a constructivist entity. These conceptualisations can be classified according to the dichotomy of essentialist and non-essentialist viewpoints. The former regards landscapes as an objective reality, whereas the latter views them as social constructs (Gailing & Leibenath, 2015). From an essentialist perspective, the use and valuation of landscapes is primarily driven by the selfish material interests of different actors. To prevent these interests from clashing and to facilitate the negotiation of compromises, institutions of governance are needed for the regulation of land uses (Arifi et al., 2017). Yet neither are these institutions free from negotiations themselves nor do they represent the superordinate public interest, as they are also the expression of the power struggle of numerous self-interested actors (Arifi et al., 2017). From this perspective, cultural landscapes are the result of competition between different land use interests that have manifested themselves over time. In this view, landscape does not have a collective value per se. From a non-essentialist perspective landscapes are constructed through social learning and processes of perception (Kühne, 2009). Through familiarisation with certain landscape images, shared beliefs and values develop over time regarding landscapes that are perceived as desirable (Arifi et al., 2017). These are contingent over time and space yet tend to be persistent over a longer period, thus making them more difficult to change (Gailing & Leibenath, 2015). These two perspectives, however, are not mutually exclusive.

In the context of RE, the essentialist perspective aligns with the NIMBY narrative, which posits that individual self-interest is the primary motivator behind opposition to RE (Devine-Wright, 2009). However, these assumptions are regarded as obsolete and simplistic, failing to capture the complex nuances of opposition (Aitken, 2010; Dear, 1992; Wolsink, 2000). In contrast, recent research has adopted a more critical approach, 'fully considering people's meaning-making about RET as socially embedded and co-constructed' (Batel, 2020, p. 2). Thus in the nexus of landscapes and renewable energies, a number of concepts have emerged that focus on the notion of place (Van Veelen & Haggett, 2017). Ranging from place attachment (Brown et al., 2015; Vorkinn & Riese, 2001), to place identity (Devine-Wright, 2009; Proshansky et al., 1983) to place-technology-fit (Devine-Wright & Howes, 2010; Međugorac & Schuitema, 2023), these theoretical frameworks all emphasise the centrality of places and landscapes, and the ways in which they are valued and imbued with meaning in diverse local contexts for understanding RE controversies. By endowing values to a specific locality, people develop a 'sense of place' which can be defined as 'the collection of meanings beliefs, symbols, values and feelings that individuals or groups associate with a particular locality' (Williams & Stewart, 1998, p. 19). These are formed through emotional bonds and familiarity with places. Identifying these bonds is challenging, as they are frequently unconscious until a threat is perceived, or a connection is lost. Furthermore, they are actively and continuously constructed. They are contingent upon cultural, historical, and spatial context (Williams & Stewart, 1998). These emotional attachments can be expressed in relation to both the specific functions of the landscape and the socially constructed meanings ascribed to it (Hidalgo & Hernández, 2001; Van Veelen & Haggett, 2017). These perspectives, situated within particular geographical contexts, emphasise the socially constructed and symbolic dimensions of places. These attachments are shaped by past and ongoing interactions between humans and their environments (Van Der Horst, 2007; Van Veelen & Haggett, 2017). Proposed energy projects have the potential to disrupt existing place attachments, depending on how well they are perceived to 'fit' with these, thereby facilitating the formation of opposition (Devine-Wright & Howes, 2010). Consequently, the assessment of a landscape is subjective and varies depending on personal experiences, interests, and learned patterns of perception. Furthermore, the benefits of a landscape to individuals are context-dependent and vary based on local values and norms (Fagerholm et al., 2012).

Although these place-based approaches offer valuable insights into the symbolic meanings attributed to landscapes by local populations, they are often deeply rooted in subjective, context-specific and non-transferable experiences (Van Veelen & Haggett, 2017). This subjectivity presents a significant challenge when attempting to systematically compare or integrate these meanings into broader planning and policy processes. Moreover, their emphasis on the local and particular may impede efforts to develop generalisable frameworks for balancing competing land use interests in the context of the energy transition. Nevertheless, the process of incorporating these meanings and values into planning and policy remains a considerable challenge (Müller et al., 2020, 2022). To address this, various conceptual frameworks have been developed that aim to translate the diverse benefits people derive from landscapes into more tangible and evaluable terms. Among these, the concept of ecosystem services (ES) has gained significant traction, as it does just that: it classifies and quantifies the contributions of natural systems to human well-being. Its original proposition was to raise awareness of the benefits nature provides to society and to support the integration of natural values into economic and political decision-making, rendering them tangible to the general public and thus encouraging people, institutions and governments to protect them (Daily, 2010). The concept of ecosystem services was first introduced by Costanza et al. (1997) and was eventually widely adopted for classifying natural assets for sustainability assessments through the Millennium Ecosystem Assessment report (MA, 2003).

Despite its conceptual strength and widespread adoption, the ES approach has been subject to considerable criticism, particularly for its limitations in addressing the full range of landscape values. First, it tends to emphasise economic valuation, often reducing complex ecological and cultural phenomena to monetary terms. This reductionism risks marginalising non-material values such as emotional attachments, symbolic meanings, and spiritual or aesthetic appreciation (Chan et al., 2012; Schröter et al., 2014). Second, the ES framework struggles to adequately represent relational and place-based values that emerge from people's lived experiences and long-term interactions with landscapes – values that are central to landscape perceptions and land use conflicts (Chan et al., 2016).

To address these challenges, planning frameworks must not only acknowledge the socio-cultural meanings embedded in landscapes but also translate these into tangible, evaluable, and communicable categories (Bastian et al., 2014). A key requirement is a concept that connects people's lived experiences and values with the material and ecological functions of landscapes, thereby enabling informed and inclusive decision-making in spatial planning (Bastian et al., 2014). This is where the concept of landscape services, which builds on the ES concept but focuses more on landscape planning and public participation processes, becomes particularly relevant.

First introduced by Termorshuizen and Opdam (2009), the concept distinguishes between the natural functions of landscapes and how people attribute value to these functions by deriving benefits from it, thereby classifying that function as a service (Haines-Young & Potschin, 2010). Landscapes are seen as 'spatial human-ecological systems delivering functions valued by humans' (Fagerholm et al., 2012, p. 422) in this concept. As such, it offers a more integrative and human-centred framework that connects biophysical landscape processes with locally embedded values, experiences, and meanings (Fagerholm et al., 2012). The intrinsic functions resulting from the physical structure of the landscape only become services when value and benefits are attached to them by humans, thus establishing the link between natural processes and human valorisation or use (Termorshuizen & Opdam, 2009). Accordingly, the differentiation between the (ecological) function of a landscape and its classification as a service is crucial for understanding the concept of landscape service. Functions represent the inherent capabilities of a landscape that persist independently of human presence, whereas services are defined by the benefits people derive from these functions, whether material, health-related, or psychological benefits. As Termorshuizen and Opdam (2009), p. 1042) aptly state, 'functions continue to exist in the absence of people, whereas services exist because people use and value the landscape'. The concept of landscape services thus includes not only natural ecosystem processes but also the value that people place on nature, helping to link natural processes with the expected human benefits and values of landscape (Termorshuizen & Opdam, 2009).

Importantly, landscape services are not only concerned with what landscapes *do*, but also with what they *mean* to people. This emphasis on subjective valuation and everyday perception makes the landscape services concept particularly useful in participatory and interdisciplinary planning contexts (Bastian et al., 2014). Because it aligns more closely with public understandings of landscapes than abstract ecological models, it provides a common ground for dialogue among planners, local stakeholders, and policymakers (Keller et al., 2019; Termorshuizen & Opdam, 2009). Especially for landscape changes associated with RE expansion, this framework enables a more socially grounded approach – one that is capable of incorporating both material and immaterial values in the negotiation of future land use.

By using common human patterns of perception, the concept of landscape services can help to facilitate discussions about landscapes. It enables actors from different sectors to discuss the same landscape category (Keller et al., 2019), creating the prerequisite for well-founded decisions on socially desirable landscape developments, including the expansion and siting of renewable energies (Termorshuizen & Opdam, 2009). Furthermore, the landscape concept is more accessible and familiar to the public than the ecosystem concept (Bastian et al., 2014). Therefore, it is more relevant for planning landscape changes, such as those in the energy transition (Fagerholm et al., 2012). The concept of landscape services can thus serve as a framework for public participation and decision-making processes, as it is based on everyday values and identities as well as tangible landscape elements in which local stakeholders can identify. It is therefore considered to be more effective for interdisciplinary cooperation and the involvement of local stakeholders than the concept of ecosystem services (Bastian et al., 2014; Fagerholm et al., 2012; Termorshuizen & Opdam, 2009).

Despite growing recognition of the importance of socio-cultural values in landscape and energy planning, the systematic integration of these values into formal planning frameworks remains a persistent challenge (Zaunbrecher & Ziefle, 2016). While place-based approaches have advanced our understanding of how individuals relate emotionally and symbolically to landscapes (Raymond et al., 2009; Stedman, 2003), their context-dependency and limited transferability limit their application in broader governance processes. Conversely, operational frameworks such as ecosystem or landscape services aim to make landscape values assessable and comparable (Haines-Young & Potschin, 2010; Schröter et al., 2014), but often struggle to account for relational, subjective and actor-specific dimensions of landscape perception (Jacobs et al., 2016; Kenter et al., 2015). As a result, existing planning tools inadequately capture how different actors assign meaning and value to landscapes, particularly in contested transformation contexts such as RE siting.

Addressing this tension requires approaches that can empirically elicit and structure diverse landscape values, while remaining sensitive to context and perception. Building on the landscape services framework, this study develops an actor-oriented, empirically grounded approach that combines spatial and statistical analyses with stakeholder perspectives to assess how landscapes are evaluated for RE development. Drawing on a structured online survey conducted among 146 stakeholders from two contrasting German planning regions – Lausitz-Spreewald and Ingolstadt – the study captures region- and actor-specific ratings of landscape suitability for wind and PV energy across 11 landscape services.

3. Materials and methods

3.1. Study area

Two regions were selected for the study: the Lausitz-Spreewald planning region in southern Brandenburg (see Figure 1b for an overview), consisting of the administrative units Cottbus, Dahme-Spreewald, Elbe-Elster, Oberlausitz-Spreewald and Spree-Neisse, and the Ingolstadt planning region in Bavaria (see Figure 1c for an overview) with the districts of Eichstätt, Ingolstadt, Neuburg-Schrobenhausen and Pfaffenhofen an der Ilm. The two regions differ in natural, socio-political and energy conditions. This allows for differentiated views of the challenges and opportunities in different regions regarding the

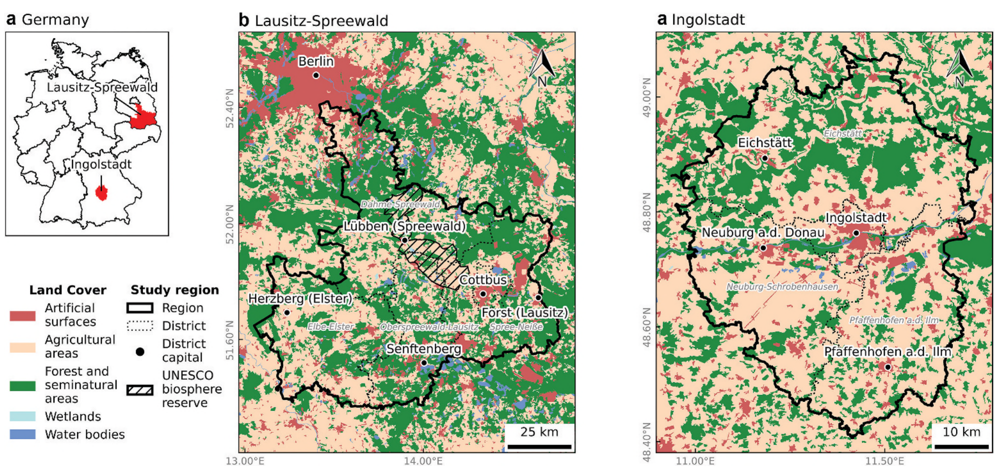


Figure 1. Location of the study areas in Germany (a) and overview of the regions Lausitz-Spreewald (b) and Ingolstadt (c) with land cover types.

availability of land for the energy transition in Germany and the assessment of the suitability of landscapes for renewable energies.

The Lausitz-Spreewald region is a very rural and peripheral region in the east of Germany, which has historically been characterised by the lignite mining industry in the Lausitz region. Due to its large size, however, the region has a very heterogeneous structure, both economically and in terms of landscape. While the north is part of Berlin’s suburban belt, the south is predominantly rural. The east of the region, particularly the district of Spree-Neiße and the area surrounding Cottbus, is characterised by the active and former lignite industry. The western district of Elbe-Elster, on the other hand, is dominated by agriculture (Nagel et al., 2021). Due to the natural diversity of the region, numerous large-scale protected areas have also been designated, such as the UNESCO Spreewald Biosphere Reserve. While demographically, the region’s population declined by 4.3% between 2010 and 2018, economically, employment and GDP have increased since 2010 (Reichert et al., 2021). In terms of physical landscape, the region is characterised equally by large areas of forest (41%) and agricultural land (40%) as well as opencast mining areas (4%) (Reichert et al., 2021).

As an East German region with a historical connection to lignite, Lausitz experienced a profound and sudden structural change after reunification, which led to the loss of around 90,000 jobs in the lignite industry within a short space of time (Noack, 2022). As a result, the period immediately after reunification was characterised by an ‘experience of collapse’ (Noack, 2022, p. 12) for many people in Lausitz. The predominant perception of Lausitz as an energy region, which still characterises the regional identity today, has its roots in the time of the German Democratic Republic, when Lausitz held a prominent position in the energy sector for the country (Noack, 2022). However, the actual economic importance of lignite for the region has decreased considerably since then and new economic centres have emerged in the energy, food, plastics, chemical and metal industries as well as in tourism (Zundel & Nagel, 2023). Nevertheless, the narrative of the energy region continues to offer potential for establishing the region as a location for renewable energies, as energy generation has been a source of identity for the people in the region for many decades (Noack, 2022, Nagel et al., 2021). The German government’s planned coal phase-out in 2038 means that the Lausitz-Spreewald region is facing another fundamental structural change in the near future.

Compared to Lausitz-Spreewald, the Ingolstadt planning region has enormous economic potential. In terms of gross domestic product, labour force and unemployment rate, the Ingolstadt planning region ranks second in Germany (Bachinger, 2018). The region benefits from knowledge-intensive and knowledge-producing companies as well as the strong presence of the automotive industry. Added to this is the close infrastructural and economic integration into the European metropolitan region of Munich, which leads to high rates of economic development, promotes national and international networking and favours the settlement of new companies. In terms of physical landscape, the region is characterised by the Altmühltal Nature Park in the north and the Donaumoos in the west. In the wider area around the two central cities of Neuburg and Ingolstadt, however, the region has a more urban character.

The expansion of wind energy in Bavaria has long been impeded by the stringent 10 H regulation, which stipulates that a proposed wind turbine must be situated a minimum distance of 10 times its height from residential areas. The enactment of this legislation in

2014 effectively halted the construction of wind energy turbines in Bavaria (Bay StMWi, 2022). As a direct consequence, in 2019, only seven wind turbines were constructed in Bavaria (Bay StMWi, 2023). Given an average height of modern turbines of 200 metres, this necessitates distances exceeding 2,000 metres from residential areas, leaving just 0.01% of the area in Bavaria available for wind energy, when also accounting for sufficient wind speeds (Langer et al., 2016). The regulation imposed further constraints on municipalities, as their authority to plan was curtailed and they were obliged to justify exceptions allowing for setback distances below the 10 H threshold (Karakislak & Schneider, 2023). The 10 H regulation underwent a relaxation in November 2022, whereby a minimum distance of 800 metres to residential areas is now permitted if the proposed wind turbine is situated within a priority or designated wind energy area. In other instances, a minimum setback distance of 1,000 metres must be observed (Bayern Innovativ, 2022).

3.2. Survey design

To quantify and operationalise regional stakeholder-specific energy landscapes on the suitability of different landscapes for renewable energies, we conducted a quantitative online survey with RE stakeholders from various fields involved in RE siting processes. Stakeholders for each of the two regions were identified through online research guided by findings from literature on actors in the RE field (Bothe & von Streit, 2017; Van De Grift & Cuppen, 2022). This yielded a selective and purposive sample for our study. The stakeholders were divided into five categories: interest groups, politics, administration, economy and civil society (see Table 1). Each category was further subdivided into specific fields corresponding to the stakeholders' field of activity (e.g. nature and species conservation). A given field can be included in different categories. For instance, the subjects of nature and species conservation, as well as water management, are addressed by both interest groups and public administrative units.

Based on the theoretical concept of Termorshuizen and Opdam (2009) and using the classification of landscape qualities and services according to Simmen and Walter (2007) and Grêt-Regamey et al. (2011), we classified three landscape qualities with a total of 11 landscape services for the two study areas, which we used for our analysis of the suitability of different landscapes for RE (see Table 2). In the context of ecological landscape quality, a distinction is made between general ecological services and the provision of habitats for animal and plant species. This differentiation is reflected in the objectives of the various protection categories. For instance, nature conservation areas are designed to protect a specific segment of the natural environment including all its services and habitats, while Natura 2000 areas, established in accordance with the EU Habitats Directive, are particularly focused on safeguarding habitats. It is important to note, however, that these areas can and frequently do overlap at least partially.

An online questionnaire comprising 22 questions on the suitability of landscapes for wind and PV energy was emailed to the selected stakeholders to assess the suitability of specific landscapes for wind and PV energy (see Appendix C for full questionnaire). In the Lausitz-Spreewald region, 225 stakeholders were identified, and in the Ingolstadt region, 204 stakeholders were invited to participate in the survey. For an overview of the sample group from both regions see Table 1. The questions in the online survey were asked for each of the landscape service categories and for the two technologies of wind and PV energy. The pattern

Table 1. Distribution of stakeholders by category and field in the two study regions.

Category	Field	Lausitz-Spreewald (*N* = 66)	Ingolstadt (*N* = 80)
Interest Groups	Nature and Species Protection	6	11
	Water Management	1	–
	Landscape Conservation	1	4
	Regional Management	1	1
	Trade Association	3	-
	Sports Club	1	–
	Tourism	1	5
	Environmental and Climate Protection	1	1
	Wind Energy	1	–
	Solar Energy	–	1
	Category total	***16***	***21***
Politics	Mayors	18	26
	Energy Policy Spokesperson (Parliament)	1	–
	District Administrator	–	1
	Regional Spokesperson	–	1
	Category total	***19***	***28***
Administration	Forestry	4	–
	Agriculture	3	–
	Nature and Species Protection	3	2
	Environmental and Climate Protection	1	7
	Monument Protection	1	1
	Water Management	4	3
	Energy Supply	–	1
	Land-Use Planning	–	3
	Category total	***16***	***17***
Economy	Project Development	5	5
	Business Development	4	2
	Agricultural Cooperative	2	–
	Energy Supply	2	2
	Category total	***13***	***9***
Civil Society	Citizens' Initiative	2	2
	Energy Cooperative	–	3
	Category total	***2***	***5***

Table 2. Landscape qualities and services.

Landscape quality	Landscape service	Exemplary data sets	Label
Aesthetic landscape qualities	Provision of space for recreation, tourism, and leisure	Recreational areas	RTL
	Place of aesthetic landscape perception	Scenic landscapes	LAS
Socio-economic landscape qualities	Agricultural areas	Agricultural areas	AGR
	Forestal land use	Forest areas	FOR
	Extraction of (mineral) raw materials	Priority areas for mineral resources	RAW
	Provision of settlement areas	Distance from residential area	RES
	Provision of mobility and infrastructure	Transport links	TIF
	Archive of the cultural history and architectural heritage	Monument protection areas	HIS
Ecological landscape qualities	Ecological services	Nature conservation areas	ECO
	Provision of habitats for animal and plant species	Natura2000 areas	PRO
	Regulation of the water cycle	Water protection zones	WAT

Source: Adapted from Grêt-Regamey et al. (2011); Simmen and Walter (2007).

for the questions was: 'How do you rate the suitability of a landscape used for [*landscape service*] as a location for the expansion of [*renewable energy technology*]?' and the respondents could answer on a continuous scale with values between 0 (not suitable at all) and 100 (very suitable). A total of 146 people took part in the online survey. Of these, 80 were from the Ingolstadt region and 66 from Lausitz-Spreewald.

To identify group-specific responses and potential clusters within the data, a non-parametric, hierarchical, and agglomerative clustering algorithm with Ward's linkage was employed on the dataset using Python (version 3.12.7) and the sklearn library. The choice of hierarchical clustering was based on the quality of the clusters it produces, its ability to detect patterns in large, high-dimensional datasets, and its independence from a predetermined number of clusters, thus reducing the need for researcher involvement (Chidananda Gowda & Krishna, 1978). The Ward linkage method ensures that the variance between all elements within a cluster is minimised, thus producing well-separated clusters (Vijaya Sharma & Batra, 2019). Prior to the application of the clustering algorithm, missing values were imputed using the k-nearest neighbours approach.

To examine differences in landscape suitability ratings for RE development, several non-parametric statistical tests were conducted. All analyses were performed using Python 3.12.7 and the scipy.stats and statsmodels libraries. For each test the statistic, *p*-value, standardized *z*-score, effect size *r* and 95% confidence intervals for *r* were calculated. Confidence intervals for *r* were computed using a normal approximation. All *p*-values were corrected for multiple testing using the Benjamini-Hochberg procedure to control the false discovery rate (FDR) at $\alpha = 0.05$ (Benjamini & Hochberg, 1995). Mann – Whitney U tests were employed to compare the suitability ratings of individual landscape service types between two independent groups, either the two study regions or the two clusters, for each energy type separately (e.g. wind, PV). Wilcoxon signed-rank tests were used for within-subject comparisons of paired ratings, such as between energy types (e.g. wind vs. PV) for the same landscape and individual. Ties and zero differences were handled appropriately by excluding them from the test. To assess differences in ratings across more than two related groups (e.g. across multiple landscapes within the same region and energy type), a Friedman test was conducted. When the Friedman test indicated significant differences ($p < .05$), post-hoc pairwise Wilcoxon signed-rank tests were applied between all landscape pairs.

To visualise the energy landscapes in their spatial implications, the classified landscape services were linked with relevant geodata and processed in Python 3.12.7. This resulted in the generation of a separate layer for each landscape service, comprising different area categories that can be attributed to that landscape service. These layers were then linked to the mean values of suitability per RE technology from the survey and rasterised to a grid size of 100 × 100 m. The resulting raster layers were then overlaid for each technology, enabling the calculation of a spatial mean value for each raster cell. For final visualisation purposes the resulting data was overlaid with factual exclusion criteria consisting of build-up areas, water bodies and steep relief, as these areas cannot be used for the deployment of RE in any case.

4. Results

The study revealed significant differences in the assessment of landscape suitability for RE generation between the two study regions. Furthermore, intraregional differences were identified for both energy types and specific landscape services, as well as between specific stakeholder groups.

4.1. Regional differences in landscape service suitability ratings for renewable energy

To assess regional differences in the perceived suitability of landscapes for RE development we conducted a Mann-Whitney-U test. The results of this test are presented in Figure 2, which shows boxplots comparing stakeholder responses from Lausitz-Spreewald (*N* = 66) and Ingolstadt (*N* = 80) across the 11 landscape service dimensions. Supporting

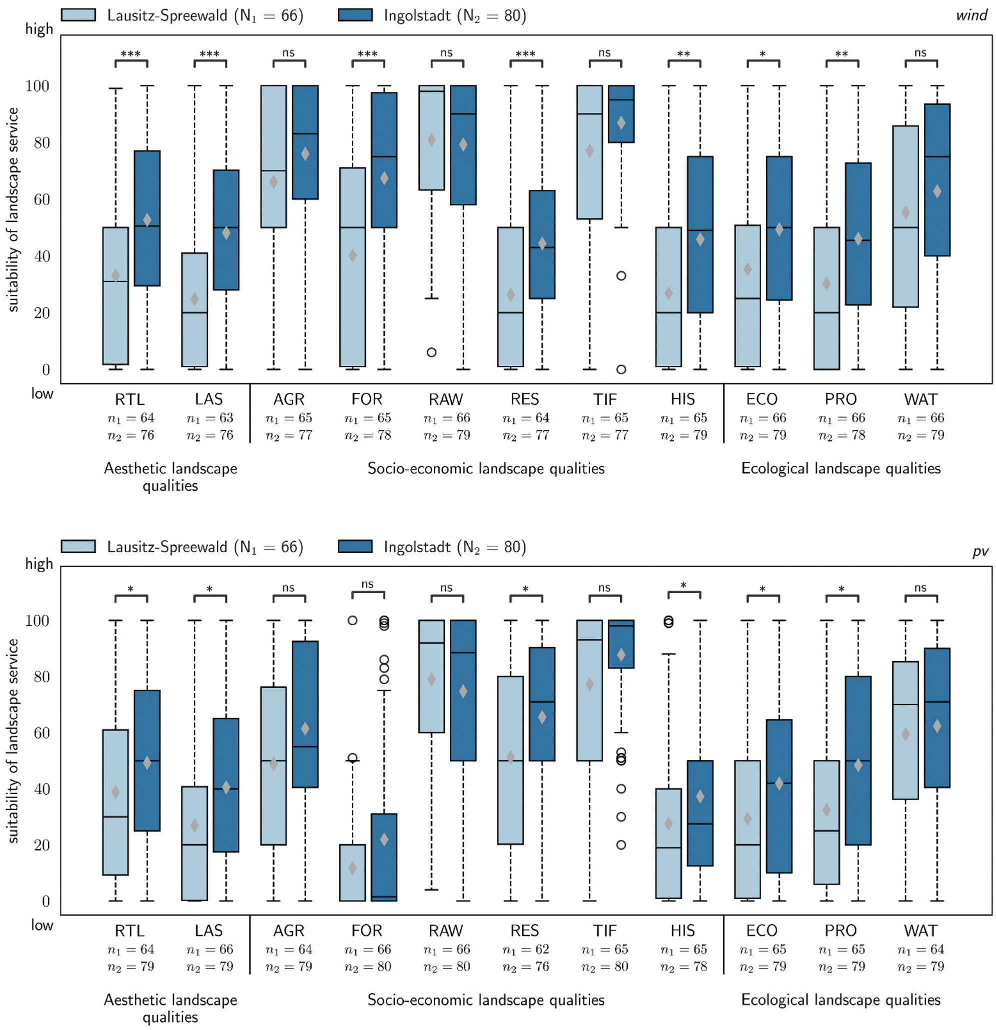


Figure 2. Comparison of landscape service suitability ratings for wind (top) and photovoltaic (bottom) energy between the two study regions across landscape quality dimensions. Boxplots display perceived suitability (0–100) of different landscape service dimensions for renewable energy development, comparing stakeholder responses from Lausitz-Spreewald (N_1 = 66) and Ingolstadt (N_2 = 80). The dimensions are grouped into aesthetic, socio-economic, and ecological landscape qualities. Diamonds represent group means. Statistical significance between the two regions for each landscape service was tested using Mann–Whitney U tests, with *p*-values corrected for multiple comparisons using the Benjamini–Hochberg procedure at an FDR of α = 0.05. Significance levels are indicated above each pair (ns = not significant, *p < .05, **p < .01, ***p < .001). Sample sizes below each category refer to valid responses per landscape service (i.e. n_1 and n_2 for each respective region).

data for the figure can be found in Appendix A/Table A1 and A2. The analysis revealed significant variations in the perceived suitability of landscape services for RE development across both regions, contingent on the specific landscape dimension and energy type. Ingolstadt consistently demonstrates higher ratings of suitability across most landscape services for wind energy in comparison to Lausitz-Spreewald. This disparity is less pronounced for PV energy, with fewer significant differences observed.

4.1.1. Aesthetic landscapes

Respondents from Ingolstadt consistently rated aesthetic landscape services (RTL, LAS) as more suitable for both wind and PV energy development than those from the Lausitz-Spreewald region. These differences were found to be highly significant for wind energy (RTL: $p < .001$ ***, $r = -0.314$; LAS: $p < .001$ ***, $r = -0.387$) and significant for PV energy (RTL: $p = .049$ *, $r = -0.185$; LAS: $p = .022$ *, $r = -0.239$) with small to moderate effect sizes.

4.1.2. Socio-economic landscapes

In terms of socio-economic landscapes, there are both similarities and differences between the two regions and energy types (see Figure 2). For wind energy, there are highly significant differences with moderate effect sizes between the two regions in the rating of the suitability of forested areas (FOR: $p < .001$ ***, $r = -0.376$), residential areas (RES: $p < .001$ ***, $r = -0.316$) and areas that serve as an archive of the cultural history and architectural heritage (HIS: $p = .001$ **, $r = -0.283$). The respondents from Ingolstadt consistently rate these landscape services as more suitable, especially forested areas. In contrast, no significant differences were identified in the ratings given by respondents for agricultural areas (AGR: $p = .148$), areas designated for raw material extraction (RAW: $p = .764$) and areas that facilitate mobility and infrastructure (TIF: $p = .148$). Collectively, these areas were rated as being highly suitable for wind energy development across both regions. For PV energy the only significant differences were identified for RES ($p = .043$ *, $r = -0.202$) and HIS ($p = .043$ *, $r = -0.195$) landscape services with small effect sizes. All other regional differences for socio-economic landscape services were non-significant, whereby forested areas were rated as very unsuitable for the development of PV energy in both regions.

4.1.3. Ecological landscapes

For landscapes exhibiting ecological qualities, significant differences with moderate effect sizes were identified for wind energy for those providing ecosystem services (ECO: $p = .012$ *, $r = -0.221$) and habitats for animal and plant species (PRO: $p = .002$ **, $r = -0.267$) across the regions. The respondents from Ingolstadt rated these regions as being more suitable to wind energy development. No significant differences were identified between the regions in terms of the suitability rating for areas that provide regulation of the water cycle (WAT), as these were rated as generally suitable in both regions. Similarly, for PV energy there are significant differences in the suitability ratings of the landscape services ECO ($p = .043$ *, $r = -0.196$) and PRO ($p = .022$ *, $r = -0.241$) while there is also no significant difference for WAT. Ratings for the landscape services with ecological qualities for PV energy are in a similar range to those for wind energy in both regions.

4.2. Intraregional differences in landscape service suitability ratings for renewable energy

To investigate intraregional differences between energy types in the perceived suitability of landscapes for RE development, we conducted a Wilcoxon signed-rank test. Furthermore, to analyse intraregional variations in the ratings of landscape services per energy, a Friedman test was conducted, subsequently followed by a post-hoc pairwise Wilcoxon signed-rank test. Results for the energy-wise comparison are shown in Table 3 for both regions.

4.2.1. Intraregional comparison between energy types per region

A comparison between wind and PV energy for each landscape service in the Lusatia-Spreewald region demonstrated a highly significant difference with large effect sizes in the rating of agricultural areas (AGR: $p < .001$ ***, $r = -0.565$), forested areas (FOR: $p < .001$ ***, $r = -0.807$) and residential areas (RES: $p < .001$ ***, $r = -0.708$). While AGR were rated more suitable for wind energy, especially FOR were rated much less suitable for PV than wind energy. Conversely, RES were rated to be more suitable for PV energy. No significant differences in the ratings of suitability for the two energy types were identified among the remaining landscape services within the Lausitz-Spreewald region.

In the Ingolstadt region the differences in ratings between wind and PV energy were also highly significant for FOR ($p < .001$ ***, $r = -0.818$) and RES ($p < .001$ ***, $r = -0.755$). Additionally, we also found significant differences between energy types in the rating for landscapes of aesthetic perception (LAS: $p = .026$ *, $r = -0.306$), agricultural areas (AGR: $p = .001$ **, $r = -0.456$), landscapes as cultural archive (HIS: $p = .008$ **, $r = -0.381$) and landscapes providing ecosystem services (ECO: $p = .012$ *, $r = -0.353$). All the remaining landscape services showed no significant differences.

4.2.2. Intraregional comparison between landscape services per region and energy type

A Friedman test was conducted to examine differences in the suitability ratings of landscape services across energy types in the region Lausitz-Spreewald. The results indicated significant differences for both wind and PV energy. For wind energy, the Friedman test yielded a statistically significant result, χ^2 (10) = 276.46, $p < .001$. For PV energy, the differences were likewise significant, χ^2 (10) = 276.31, $p < .001$.

Follow-up pairwise comparisons using Wilcoxon signed-rank tests with FDR correction revealed multiple statistically significant differences between individual landscape services as shown in Figures 3 and 4 (see Appendix A/Table A3 and Table A4 for full pairwise comparisons).

Pairwise comparisons of landscape service ratings for wind energy in Lausitz-Spreewald revealed numerous statistically significant differences, particularly between socio-economic services and ecological or cultural-heritage-related services (see Figure 3). Among the 55 pairwise comparisons, 41 showed statistically significant differences. Agricultural land (AGR) received one of the highest ratings and differed significantly from all other landscape services. Similarly, highly rated infrastructural landscapes (TIF) and raw material extraction sites (RAW) also showed highly significant differences with strong effect sizes (r between −0.75 and −0.86) from all other landscape services except between each other, suggesting a similar perception of their high suitability for wind

Table 3. Wilcoxon signed-rank test results for intraregional differences in landscape service ratings between energy types in the two study regions.

	Lausitz-Spreewald (N = 66)						Ingolstadt (N = 80)					
Landscape service	*n*	W-statistic	z-score	Effect size (r)	95% CI	*p* value	*n*	W-statistic	z-score	Effect size (r)	95% CI	*p* value
RTL	47	352	−2.243	−0.327	[−0.613, −0.041]	.055	61	818	−0.916	−0.117	[−0.368, 0.134]	.403
LAS	47	504	−0.635	−0.093	[−0.379, 0.193]	.642	64	674	−2.444	−0.306	[−0.551, −0.061]	.026*
AGR	50	223	−3.996	−0.565	[−0.842, −0.288]	<.001***	63	479	−3.622	−0.456	[−0.703, −0.209]	.001**
FOR	47	41	−5.529	−0.807	[−1, −0.521]	<.001***	71	75	−6.893	−0.818	[−1, −0.585]	<.001***
RAW	40	374	−0.477	−0.075	[−0.385, 0.234]	.657	52	509	−1.635	−0.227	[−0.498, 0.045]	.160
RES	52	128	−5.104	−0.708	[−0.98, −0.436]	<.001***	64	137	−6.039	−0.755	[−1.0, −0.51]	<.001***
TIF	37	297	−0.822	−0.135	[−0.457, 0.187]	.565	52	533	−1.416	−0.196	[−0.468, 0.075]	.215
HIS	44	457	−0.443	−0.067	[−0.362, 0.229]	.657	61	531	−2.977	−0.381	[−0.632, −0.13]	.008**
ECO	42	325	−1.575	−0.243	[−0.546, 0.059]	.210	62	580	−2.78	−0.353	[−0.602, −0.104]	.012*
PRO	45	403	−1.292	−0.193	[−0.485, 0.1]	.308	59	765	−0.902	−0.117	[−0.373, 0.138]	.403
WAT	37	198	−2.316	−0.381	[−0.703, −0.058]	.055	59	869	−0.117	−0.015	[−0.27, 0.24]	.907

Results of Wilcoxon signed-rank tests comparing paired ratings of landscape services between energy types (e.g. PV vs. Wind) within each region: Lausitz-Spreewald ($N = 66$) and Ingolstadt ($N = 80$). Shown are the number of valid paired cases (*n*), test statistic (W), standardized z-score, effect size (r), and 95% confidence intervals (CI) for r. Asterisks indicate significance after FDR correction: *$p < .05$, **$p < .01$, ***$p < .001$. CI limits are truncated at −1 or 1 when applicable.

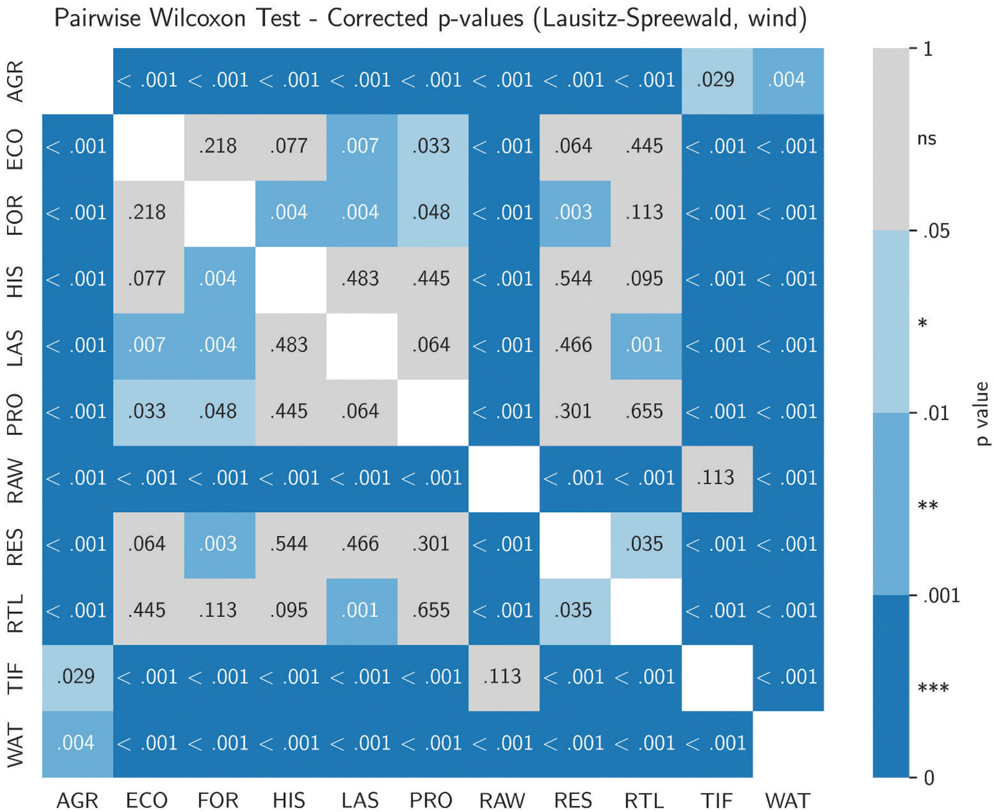


Figure 3. Pairwise Wilcoxon rank-sum test results with adjusted p-values for perceived suitability of landscape services for wind energy in Lausitz-Spreewald. The heatmap displays significance levels for pairwise comparisons of landscape service suitability ratings. Darker shading indicates lower p-values (significant differences at $p < .05$ after adjustment).

energy. In particular, AGR was rated significantly more suitable than residential areas (RES: $p < .001$ ***, $r = -0.859$), aesthetic landscapes (LAS: $p < .001$ ***, $r = -0.857$), historical archive landscapes (HIS: $p < .001$ ***, $r = -0.85$) and protected habitat areas (PRO: $p < .001$ ***, $r = -0.821$). Also, the rating of forested areas differed significantly from other services like RAW ($p < .001$ ***, $r = -0.853$) and TIF ($p < .001$ ***, $r = -0.857$) with exception of ECO ($p = .218$) and RTL ($p = .113$). Recreational and touristic areas (RTL), aesthetic landscapes (LAS), protected habitat areas (PRO), ecological landscapes (ECO), historical archive landscapes (HIS), and residential areas (RES) were rated among the least suitable for wind energy deployment. Multiple comparisons between these lower-rated landscape service types were non-significant. For example, ecological landscapes (ECO) and historical archive landscapes (HIS) were rated similarly low ($p = .077$, $r = -0.266$), as were HIS and LAS ($p = .483$, $r = -0.11$) and PRO and RTL ($p = .655$, $r = -0.068$). Such findings indicate a general consensus around the low suitability of more sensitive or protected landscapes, without clear distinctions between them.

Similar patterns emerged for PV energy in Lausitz-Spreewald, although with fewer non-significant results (see Figure 4). Among the 55 pairwise comparisons, 45 showed statistically significant differences. AGR was rated as being significantly more suitable than FOR

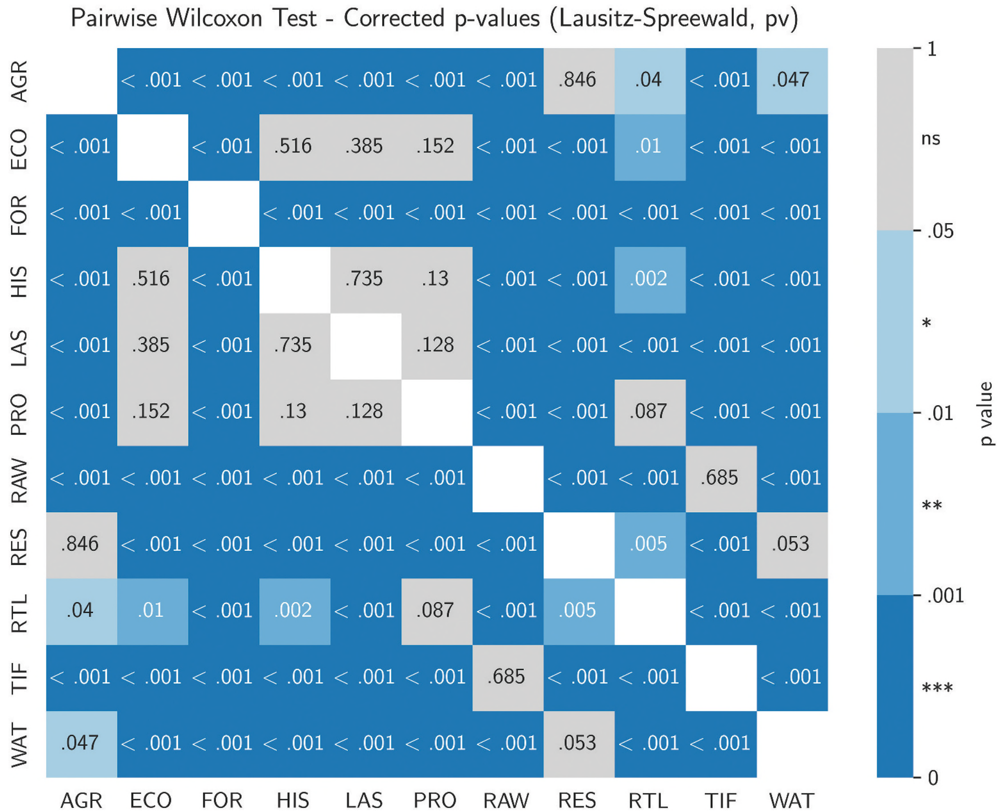


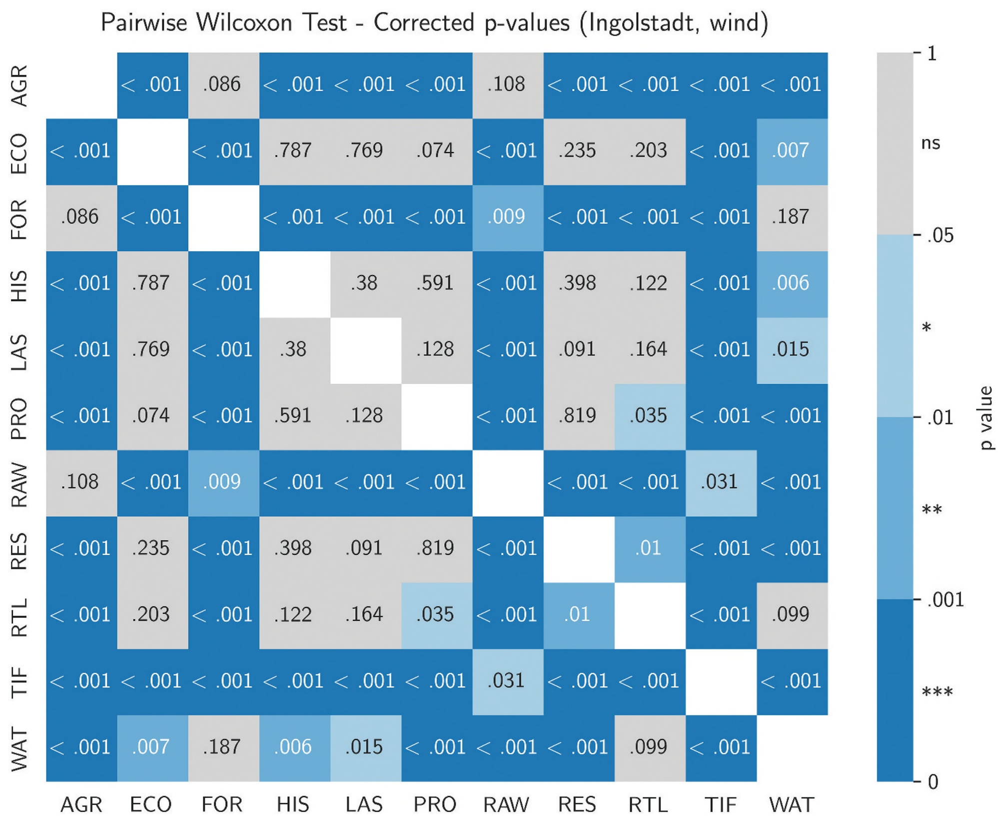
Figure 4. Pairwise Wilcoxon rank-sum test results with adjusted p-values for perceived suitability of landscape services for photovoltaic energy in Lausitz-Spreewald. The heatmap displays significance levels for pairwise comparisons of landscape service suitability ratings. Darker shading indicates lower p-values (significant differences at $p < .05$ after adjustment).

($p < .001$ ***, $r = -0.867$) and HIS ($p < .001$ ***, $r = -0.641$), and comparable to TIF ($p < .001$ ***, $r = -0.709$) and RAW ($p < .001$ ***, $r = -0.738$). However, AGR and RES did not differ significantly ($p = .846$), suggesting comparable suitability. Forested areas (FOR) received the lowest rating and were found to differ significantly compared to all other landscape services (r between 0.65 and 0.86). In a similar manner, TIF and RAW landscapes demonstrated a significant difference compared to all other landscape services except for each other.

Again, those landscapes rated with lower suitability (RTL, LAS, HIS, ECO, PRO) demonstrated several non-significant comparisons. For instance, ecological landscapes (ECO) do not differ significantly from HIS ($p = .516$), LAS ($p = .385$) and PRO ($p = .152$). The exception are recreational and touristic areas (RTL), that differ significantly from ECO ($p = .001$ **, $r = -0.408$), HIS ($p = 0.002$**, $r = -0.474$) and LAS ($p < .001$***, $r = -0.689$). Historical archive landscapes (HIS) do also not differ significantly from LAS ($p = .7.35$) and PRO ($p = .130$).

For the Ingolstadt region the results of the Friedman test also indicated significant differences for both wind and PV energy. For wind energy, the Friedman test yielded a statistically significant result with χ^2 (10) = 245.677, $p < .001$. For PV energy, the differences were likewise significant with χ^2 (10) = 267.614, $p < .001$. Follow-up pairwise comparisons using Wilcoxon signed-rank tests with FDR correction revealed multiple statistically significant differences between individual landscape services as shown in Figures 5 and 6 (see Appendix A/Table A5 and Table A6 for full pairwise comparisons).

Among the 55 pairwise comparisons, 37 showed statistically significant differences for wind energy (see Figure 5). Agricultural areas (AGR) were consistently rated as more suitable for wind energy than residential areas (RES: $p < .001$ ***, $r = -0.85$), protected habitat areas (PRO: $p < .001$ ***, $r = -0.779$), and aesthetic areas (LAS: $p < .001$ ***, r = –0.749), with strong effects. No significant differences were found for AGR in comparison to forested areas (FOR: $p = .086$) and raw material extraction areas (RAW: $p = .108$), indicating similar perceptions of higher suitability for these landscape services. Transport infrastructure (TIF) and raw material extraction areas (RAW) exhibited significant differences to almost all other landscape services with strong effect sizes (e.g. TIF-ECO: $p < .001$ ***, $r = -0.84$; TIF-HIS: $p < .001$ ***, $r = -0.855$). In contrast to the Lausitz-Spreewald region, a significant disparity between both TIF and RAW ($p = .031$ *, $r = -0.374$) was observed, albeit with a comparatively reduced effect size. Similarly to the Lausitz-Spreewald region, landscape services from the groups of aesthetic landscape qualities and cultural or



	AGR	ECO	FOR	HIS	LAS	PRO	RAW	RES	RTL	TIF	WAT
AGR		< .001	.086	< .001	< .001	< .001	.108	< .001	< .001	< .001	< .001
ECO	< .001		< .001	.787	.769	.074	< .001	.235	.203	< .001	.007
FOR	.086	< .001		< .001	< .001	< .001	.009	< .001	< .001	< .001	.187
HIS	< .001	.787	< .001		.38	.591	< .001	.398	.122	< .001	.006
LAS	< .001	.769	< .001	.38		.128	< .001	.091	.164	< .001	.015
PRO	< .001	.074	< .001	.591	.128		< .001	.819	.035	< .001	< .001
RAW	.108	< .001	.009	< .001	< .001	< .001		< .001	< .001	.031	< .001
RES	< .001	.235	< .001	.398	.091	.819	< .001		.01	< .001	< .001
RTL	< .001	.203	< .001	.122	.164	.035	< .001	.01		< .001	.099
TIF	< .001	< .001	< .001	< .001	< .001	< .001	.031	< .001	< .001		< .001
WAT	< .001	.007	.187	.006	.015	< .001	< .001	< .001	.099	< .001	

Figure 5. Pairwise Wilcoxon rank-sum test results with adjusted p-values for perceived suitability of landscape services for wind energy in Ingolstadt. The heatmap displays significance levels for pairwise comparisons of landscape service suitability ratings. Darker shading indicates lower p-values (significant differences at $p < .05$ after adjustment).

ecological qualities that were rated as less suitable did not attain statistical significance when compared to each other (e.g. ECO-HIS: $p = .787$; HIS-PRO: $p = .591$), suggesting a shared perception of their comparable lower suitability.

Even more pronounced differences were found for PV, with 48 of 55 comparisons reaching significance (see Figure 6). Several pairings indicated strong significant differences, including AGR – FOR ($p < .001$ ***, $r = -0.819$), FOR – RAW ($p < .001$ ***, $r = -0.840$), and HIS – TIF ($p < .001$ ***, $r = -0.859$). The landscape services that exhibited the most significant differences in ratings compared to all others were FOR, RAW, and TIF. In contrast, the latter two services were rated as highly suitable, while FOR was rated as highly unsuitable. Agricultural areas (AGR) are perceived as suitable for PV and exhibit no significant difference compared to RES ($p = .268$) and WAT ($p = .442$), but all other landscape services. The remaining non-significant pairs include ECO – LAS ($p = .480$), ECO – HIS ($p = .131$), HIS – LAS ($p = .242$), PRO – RTL ($p = .5$) and RES – WAT ($p = .536$), suggesting a limited shared perception of the suitability of cultural, aesthetic or ecological valuable landscapes for PV. Differences were particularly pronounced in comparisons such as ECO – RES ($p < .001$ ***, $r = -0.642$) and LAS – RES ($p < .001$ ***, $r = -0.726$), highlighting stronger preferences for residential proximity for PV.

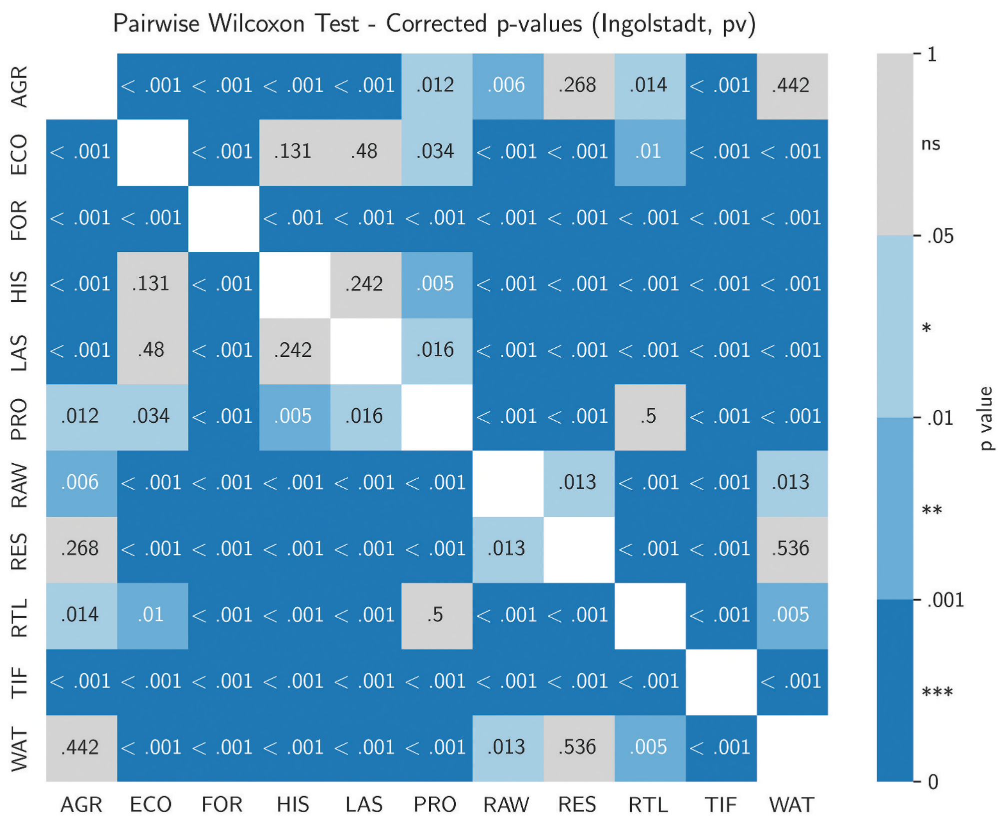


Figure 6. Pairwise Wilcoxon rank-sum test results with adjusted p-values for perceived suitability of landscape services for photovoltaic energy in Ingolstadt. Note. The heatmap displays significance levels for pairwise comparisons of landscape service suitability ratings. Darker shading indicates lower p-values (significant differences at $p < .05$ after adjustment).

4.3. Cluster analysis

The hierarchical cluster analysis identified two distinct clusters in each of the two study regions. Cluster 1, characterised by consistently lower suitability ratings, is henceforth referred to as the *restrictive* cluster, whereas Cluster 2, with markedly higher ratings, is termed the *supportive* cluster. For the Lausitz-Spreewald region, the restrictive cluster comprised 34 respondents, and the supportive cluster included 32 respondents. In the Ingolstadt region, the restrictive cluster included 45 respondents, while the supportive cluster consisted of 35 respondents. To assess differences between the clusters and control the cluster building, Mann-Whitney U tests were conducted. The results revealed highly significant differences ($p < .001$) across most landscape services and energy types in both regions, with the exception of FOR and PV energy in the Ingolstadt region, where no statistically significant differences were observed, as these areas were unequivocally rated as unsuitable by both clusters. Boxplots illustrating the cluster-wise comparisons per region and energy type are presented in Figures 7–10. Supporting data for these figures can be found in the Appendix A/Tables A7–10.

Figure 7 presents the comparison of landscape service suitability ratings for wind energy between the restrictive ($n = 34$) and supportive cluster ($n = 32$) in the Lausitz-Spreewald region. Across all landscape services, the supportive cluster reported substantially higher suitability ratings than the restrictive cluster. Differences were statistically significant ($p < .001$) for all landscape services. Effect sizes ranged from medium to very large, with the strongest effects observed for ecological landscapes (ECO, $r = -0.792$), protected habitat areas (PRO, $r = -0.682$), and aesthetic landscape qualities such as recreational and touristic landscapes (RTL, $r = -0.716$) and aesthetic landscapes (LAS, $r = -0.673$). Confidence intervals consistently indicated robust group differences. Figure 8 summarizes the same comparison for PV energy. Again, respondents in the supportive cluster rated landscape services significantly more suitable for PV implementation across all dimensions. The differences were statistically significant for every landscape service (all $p < .001$). The largest effect sizes

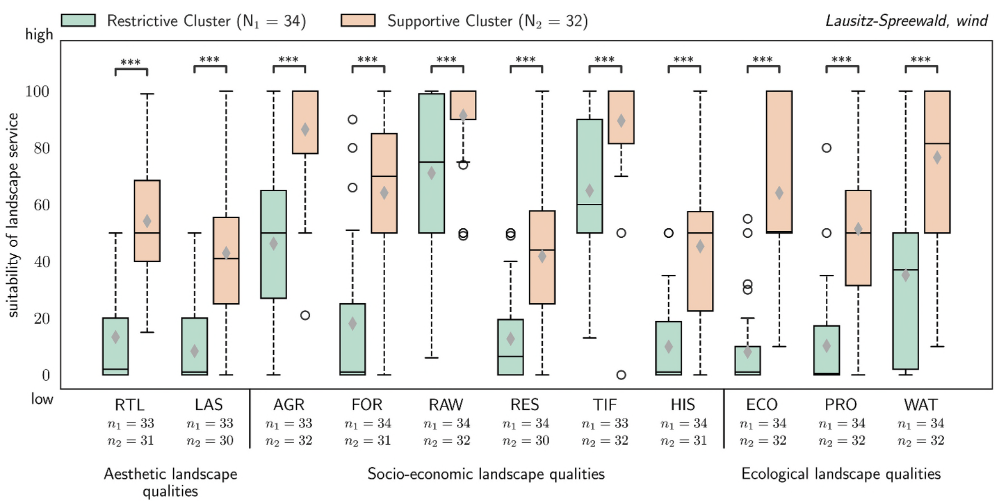


Figure 7. Comparison of landscape service suitability ratings for wind energy between the two clusters across landscape quality dimensions in Lausitz-Spreewald.

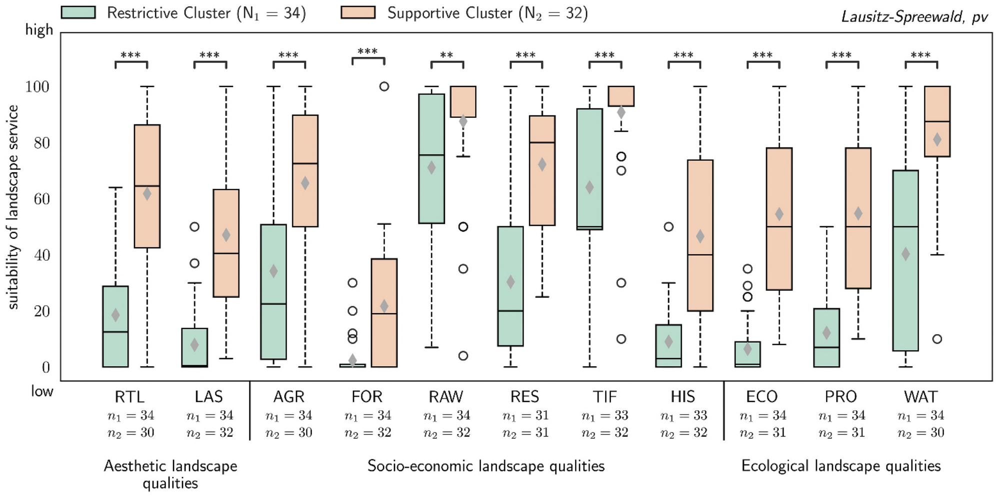


Figure 8. Comparison of landscape service suitability ratings for photovoltaic energy between the two clusters across landscape quality dimensions in Lausitz-Spreewald.

were found for ecological landscapes (ECO, $r = -0.787$), protected habitat areas (PRO, $r = -0.730$), and aesthetic landscapes (LAS, $r = -0.723$), suggesting a consistent pattern of divergence in perception between the two clusters. Even for services with smaller mean differences – such as raw materials (RAW) and forestry (FOR) – effects were moderate and significant. These findings confirm a systematic divergence in perception between the clusters, with respondents from the supportive cluster consistently perceiving landscape services as more compatible with both wind and PV energy development.

Figure 9 reports differences in suitability ratings for wind energy between the restrictive cluster ($n = 45$) and the supportive cluster ($n = 35$) in the Ingolstadt region. The

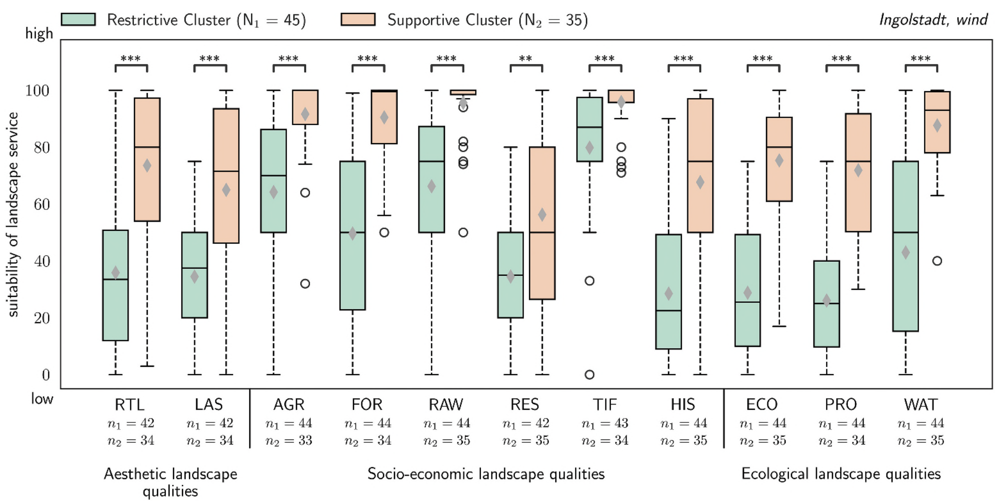


Figure 9. Comparison of landscape service suitability ratings for wind energy between the two clusters across landscape quality dimensions in Ingolstadt.

supportive cluster consistently provided higher ratings across all landscape services, with all differences reaching statistical significance ($p < .001$). Effect sizes were generally medium to large, most notably for ecological landscapes (ECO, $r = -0.739$), protected habitat areas (PRO, $r = -0.758$), and forested areas (FOR, $r = -0.690$). These results mirror the pattern found in the Lausitz-Spreewald region, indicating a robust cluster structure in terms of suitability perceptions.

Figure 10 displays the corresponding results for PV energy. As with wind, the supportive cluster rated almost all landscape services as more suitable for PV deployment. Differences were statistically significant ($p < .05$) for all but forested areas (FOR, $p = .059$), where no significant difference emerged. The most pronounced effects were again observed for protected habitat areas (PRO, $r = -0.677$), historical archive landscapes (HIS, $r = -0.609$), and ecological landscapes (ECO, $r = -0.602$). These findings confirm the presence of systematically differing perspectives within the regional population. Members of the supportive cluster perceive landscapes as substantially more compatible with RE development than those in the restrictive cluster – across both wind and PV, and across multiple landscape services.

4.3.1. Group-specific responses – Lausitz-Spreewald

To better understand group-specific response behaviour, the distribution of stakeholder groups with at least five respondents across the two cluster groups is described below. A comprehensive overview is provided in Appendix B. Among the surveyed mayors ($n = 16$) from the Lausitz-Spreewald region, approximately 61 % were assigned to the supportive cluster, suggesting a generally favourable stance toward RE expansion. In contrast, all respondents from the nature conservation and species protection sector ($n = 9$) are part of the restrictive cluster, indicating a markedly critical attitude toward both wind and PV development. Similarly, 80 % of respondents from water management ($n = 5$) were assigned to the restrictive cluster, reflecting comparable concerns regarding landscape suitability. Conversely, stakeholders from the project development sector ($n = 5$) were uniformly assigned to the supportive cluster, indicating a consistent openness toward landscape use for RE purposes.

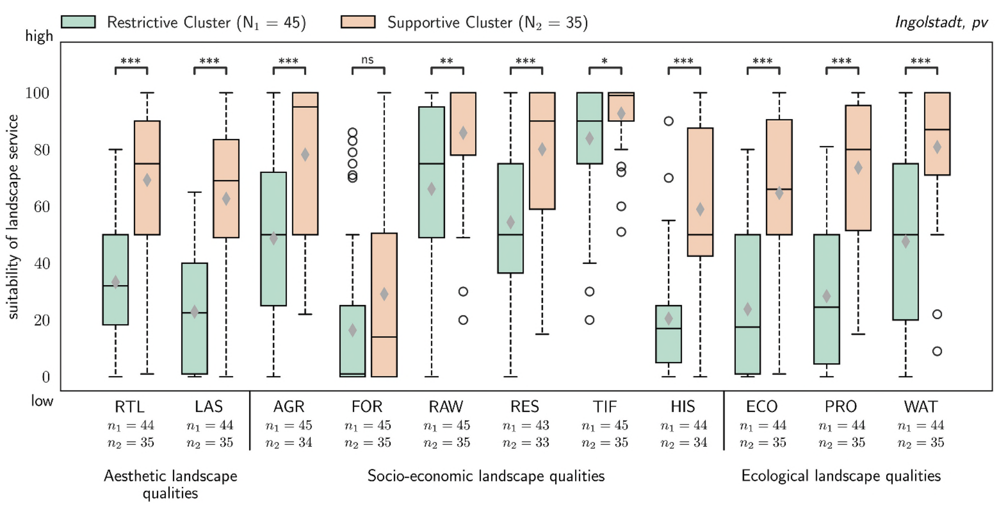


Figure 10. Comparison of landscape service suitability ratings for photovoltaic energy between the two clusters across landscape quality dimensions in Ingolstadt.

4.3.2. Group-specific responses – Ingolstadt

In the Ingolstadt region, the distribution of stakeholder groups shows a somewhat different pattern. Of the 26 surveyed mayors, 57 % were assigned to the restrictive cluster, suggesting a more cautious stance toward RE expansion compared to Lausitz-Spreewald. A majority of nature and species conservation stakeholders ($n = 11$) were likewise classified in the restrictive cluster (72 %), confirming a broadly critical perspective within this group. In contrast, 62 % of stakeholders from the environmental and climate protection sector ($n = 8$) were found in the supportive cluster, suggesting a more positive attitude toward RE development. As in Lausitz-Spreewald, the project development group ($n = 5$) was entirely part of the supportive cluster, indicating consistent support across both regions. Meanwhile, respondents from the tourism sector ($n = 5$) were predominantly classified in the restrictive cluster (80 %), reflecting a generally sceptical stance toward the suitability of landscapes for RE infrastructure.

4.4. Cartographic visualisation of quantitative stakeholder energy landscapes

The cartographic representation of stakeholder-assessed landscape suitability for RE deployment is shown in Figure 11 (Ingolstadt) and Figure 12 (Lausitz-Spreewald). In the Lausitz-Spreewald region, areas officially designated for wind energy by the regional planning authorities are also displayed. Such designations, however, are not available for the Ingolstadt region. A regional comparison reveals that overall suitability values are higher in Ingolstadt. When comparing technologies within regions, landscapes are

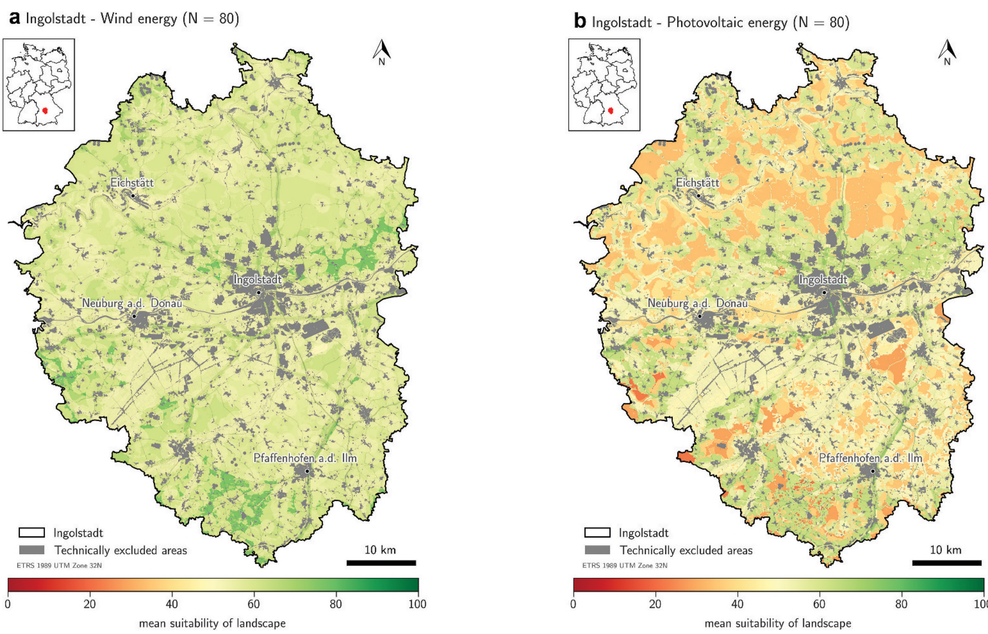


Figure 11. Stakeholder perspectives on the suitability of landscapes for (a) wind energy (min = 44.39, max = 86.91) and (b) photovoltaic energy (min = 21.95, max = 87.75) in the Ingolstadt region.

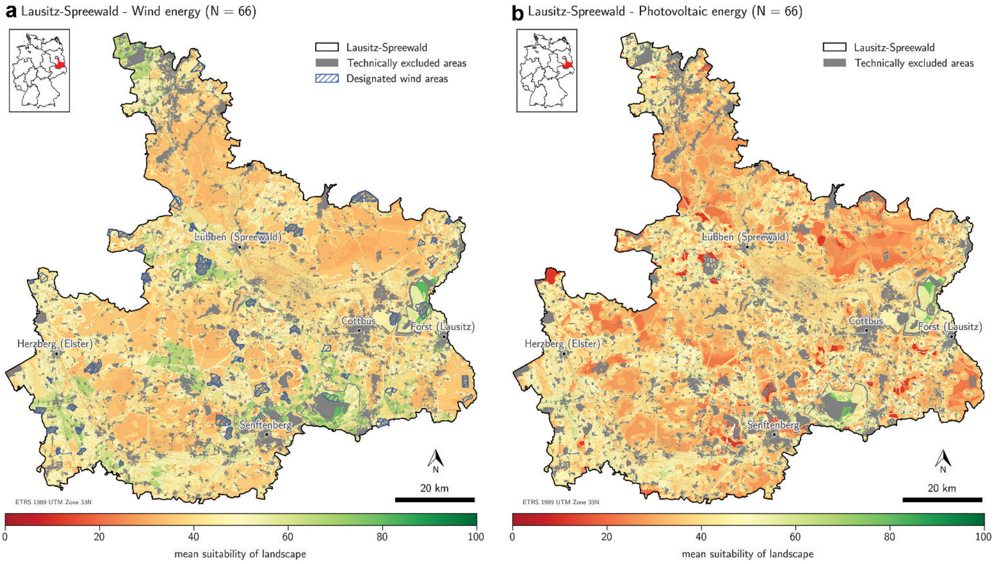


Figure 12. Stakeholder perspectives on the suitability of landscapes for (A) wind energy (min = 44.39, max = 86.91) and (B) photovoltaic energy (min = 21.95, max = 87.75) in the Lausitz-Spreewald region.

generally perceived as more suitable for wind energy than for PV systems. In the Lausitz-Spreewald region, the most suitable areas for RE development from the stakeholders' perspective are located near the open-cast lignite mining zones to the east and south of Cottbus, some of which remain operational. Another potentially suitable area lies in the northern part of the region, characterized by low settlement density, agricultural land use, and proximity to Berlin and the Berlin Brandenburg Airport. Forested areas are consistently rated as least suitable for PV development, while no distinct spatial pattern emerges for wind energy suitability in this region. In contrast, the Ingolstadt region lacks prominent landscape features such as open-cast mining, resulting in a less pronounced spatial differentiation between suitable and unsuitable areas. Landscapes deemed unsuitable for PV systems are mainly forested and subject to overlapping landscape protection categories. Conversely, agricultural areas are frequently rated as suitable for PV deployment. A similar, though less distinct, pattern is observed for wind energy, with suitability again aligning more often with agricultural land use.

5. Discussion

The transition to RE requires reconciling the pure technical potential with socially negotiated landscape values. In our study we sought to advance this challenge by developing and applying a framework to operationalise stakeholder-specific energy landscapes and their perceived suitability (RQ1), assessing regional and group-based differences in perceived landscape suitability for RE (RQ2), and evaluating how these findings can refine existing RE siting frameworks (RQ3). The results demonstrate that landscape suitability is not a purely objective property, but rather a multidimensional construct, contingent on contextual and regional factors. We first discuss the methodological implications of quantifying stakeholder perceptions, then analyse regional and intra-regional divergences, and finally propose pathways to integrate these findings into RE planning.

Perceived landscape suitability was quantified using stakeholder ratings across 11 dimensions of landscape services, encompassing aesthetic, socio-economic, and environmental qualities. This approach enabled the development of a comprehensive framework for capturing stakeholder-specific perceptions of energy landscapes. Unlike purely technical suitability assessments, our approach captured statistically significant differences in perceived suitability between study regions, energy types, and stakeholder groups. Our results demonstrate that stakeholder perceptions of RE suitability are not only measurable and context-dependent but also inherently multidimensional – with divergent perceptions of suitability emerging across landscape types (e.g. forests vs. agricultural lands), energy technologies (e.g. wind vs. solar) and stakeholder groups (e.g. nature conservationists vs. climate protectors). This finding aligns with the growing recognition in energy transition research that landscape suitability and siting decisions cannot be reduced to technical or economic criteria alone (Devine-Wright, 2011; Klok et al., 2023; Wüstenhagen et al., 2007). Our quantification of social perceptions thus provides a replicable framework to bridge this gap in renewable energy siting methodologies that traditionally prioritized technical and economic criteria while marginalizing social perceptions.

Inter- and intra-regional comparisons revealed systematic differences in perceptions of landscape suitability across different dimensions. While stakeholders in Ingolstadt consistently rated landscapes as more suitable for RE (especially wind energy), Lausitz-Spreewald showed stronger polarisation, with post-mining and infrastructural landscapes considered highly suitable, while ecologically sensitive, recreational or aesthetically pleasing areas were considered less suitable. Perceptions of PV suitability were more regionally homogeneous and showed fewer significant differences, coupled with smaller effect sizes. Regional differences were mainly observed in landscapes such as aesthetic and protected habitats.

A key finding of our results was the inter-regional consensus on industrial and infrastructure areas as suitable RE locations. These sites offer a strong place-technology fit (Devine-Wright & Howes, 2010), as their industrial character matches the technological imprint of RE infrastructure (Batel et al., 2015). This is consistent with Jobert et al. (2007), who showed that urban and industrial landscapes are socially preferred for RE deployment. Moreover, this preference may reflect a form of place-protective behaviour (Devine-Wright, 2009; Salak et al., 2021), where stakeholders implicitly protect natural and rural landscapes by directing RE development towards already industrialised areas.

The higher suitability ratings for recreational and aesthetic landscapes in Ingolstadt may initially appear contradictory, given the widespread concerns about the visual impact of wind turbines as unaesthetic and detrimental to the scenic quality of landscapes (Ioannidis & Koutsoyiannis, 2020; Petrova, 2016). However, design mitigation (e.g. visibility, colour and fractality; Torres Sibille et al., 2009), choice of landscape siting (Ek & Persson, 2014) and the moral association of RE with sustainability (Kirchhoff et al., 2022) have been shown to reduce aesthetic objections and improve social acceptance of wind turbines. Research indicates that wind energy proponents often prioritise climate benefits over landscape changes (Molnarova et al., 2012; Salak et al., 2021), and turbines can actually gain acceptance in scenic and touristic areas (Brudermann et al., 2019; Lothian, 2020). This suggests that acceptance of trade-offs does not necessarily indicate the absence of adverse visual impacts.

Beyond industrial areas, two notable consensus areas emerged. Agricultural landscapes were widely deemed suitable for wind energy, whereas residential peripheries were preferred for PV deployment. In contrast, forest areas represented a more contested landscape: While these landscapes were universally rejected for PV deployment, they were considered conditionally suitable for wind energy in Ingolstadt but not in Lausitz-Spreewald, suggesting regional differences in perceived compatibility.

These results reveal a clear dichotomy in the perceived suitability of landscapes, with those that are functionally defined primarily by economic criteria, including agricultural land (AGR), infrastructure areas (TIF) and those designated for raw material extraction (RAW), consistently receiving higher ratings than those with cultural-ecological value, including protected habitat areas (PRO), ecologically valuable areas (ECO), aesthetically perceived landscapes (LAS), recreational-touristic areas (RTL) and historical archive landscapes (HIS). This stark contrast between utilitarian and conservation-worthy landscapes emerged clearly for both wind and PV energy across regions, highlighting how stakeholder perceptions prioritise functional landscapes for energy development while protecting culturally and ecologically sensitive areas. These findings suggest that RE planning should place priority on industrial and agricultural zones as 'acceptance corridors' while employing design mitigation strategies in scenic areas. Furthermore, in specific cases such as the Lausitz-Spreewald region, areas already burdened by extensive landscape change, such as post-mining landscapes (Deshaies, 2018; Krümmelbein et al., 2012), can be considered as 'sacrifice zones' suitable for RE deployment while preserving other landscapes deemed worthy of protection. However, while post-mining landscapes can provide low-conflict sites, its use must avoid compounding historical burdens to serve overall energy justice (Jenkins et al., 2016).

Our cluster analysis revealed a consistent bimodal distribution of stakeholder groups across both regions, reflecting an entrenched division where economic actors aligned with the supportive cluster, while nature conservationists were aligned with the restrictive cluster. Notably, mayors exhibited regional divergence as the majority (61%) in Lausitz expressed a supportive stance, while in Ingolstadt, the majority (57%) adopted a restrictive position. As shown by Karakislak and Schneider (2023), mayors are key actors in RE transitions as they can either support or oppose local projects and thus significantly shape the local discourse and responses to RE projects. The support of mayors can even be considered as a prerequisite for the initiation of wind energy projects (Karakislak & Schneider, 2023). In the case of Lausitz-Spreewald, mayors serve as important intermediaries in the transition from fossil to renewable energy production (Gürtler & Herberg, 2023). The divergence between climate-focused (supportive) and nature conservation-focused (restrictive) environmental groups in the clusters illustrates the green-green dilemma, which can lead to opposition to wind energy projects due to their impact on biodiversity (Burch et al., 2020). Despite the findings of Dunnett et al. (2022) demonstrating, on a global scale, minimal overlap between future wind and solar energy developments and conservation areas, it is imperative that these opposing views be resolved for the successful implementation of wind energy projects in local contexts. As posited by Voigt et al. (2019), a pragmatic approach to resolving this dispute would entail the implementation of technical cut-in speeds for wind turbines, with the objective of mitigating avian mortality.

In summary, the findings of this study, in conjunction with the operationalisation of stakeholders' perceived landscape suitability for RE, have the potential to enhance existing RE siting processes by the following means: 1) by providing a replicable methodology for integrating stakeholder-specific perceptions of landscape suitability in RE siting decisions; 2) by revealing regional particularities and how these shape the diverse acceptance of RE; and 3) by uncovering value-driven conflicts between stakeholder groups and respective landscape categories. The proposed approach provides a clear framework on how to identify possible consensus areas between different stakeholder groups that can serve as 'acceptance corridors' for RE development, but also on 'red lines', i.e. areas that are universally rejected for any RE development.

While this study provides valuable insights into stakeholder perceptions of landscape suitability for RE, several important limitations must be acknowledged. First, our methodology assessed relative suitability between landscapes rather than a absolute thresholds for development, which limits direct application to siting decisions without additional technical analysis. Second, while our sample captured a diverse range of stakeholder perspectives, some professional groups were under-represented, and caution should be exercised in generalising findings to all members of these categories.

The static nature of our assessment is a third limitation, as it cannot account for how perceptions might evolve during the energy transition or in response to demonstration projects and policy changes. Fourth, the interpretation of neutral or low suitability ratings remains ambiguous, as these could indicate either genuine ambivalence or measurement limitations in distinguishing between similarly unsuitable options.

Finally, our study did not explore how specific mitigation measures or compensation schemes might alter perceptions of suitability for contested landscapes. Future research should address these limitations through longitudinal designs, discrete choice experiments and participatory methods, building on the comparative framework developed here.

6. Conclusion

To date, there is no standardised method for identifying suitable sites for RE development from the perspective of key stakeholders in the energy transition. Our study shows that the concept of landscape services can be used effectively to quantitatively assess the suitability of specific landscapes for RE. Either region-, energy-, landscape-specific and group-specific assessments of landscapes can be uncovered, which can help to develop locally tailored solutions with a high level of social acceptance for the expansion of RE. By comparing divergent opinions and reflecting the results to local stakeholders, it may be possible to resolve existing land conflicts in the future and develop alternative land use concepts that consider a variety of different values and expectations of the landscape for the energy transition based on landscape services. In addition, participatory approaches and tools, such as participatory mapping, can be integrated into the process to further validate the suitable areas to be identified. In further steps, the results can be used in concrete planning projects to develop, together with local stakeholders, common energy futures and spatial visions for the energy transition, while acknowledging local contexts, norms and values, which are reflected in differing landscape perception and valuation.

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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