

# A Systematic Overview of Energy Landscapes: Cognition, Typologies, and Development

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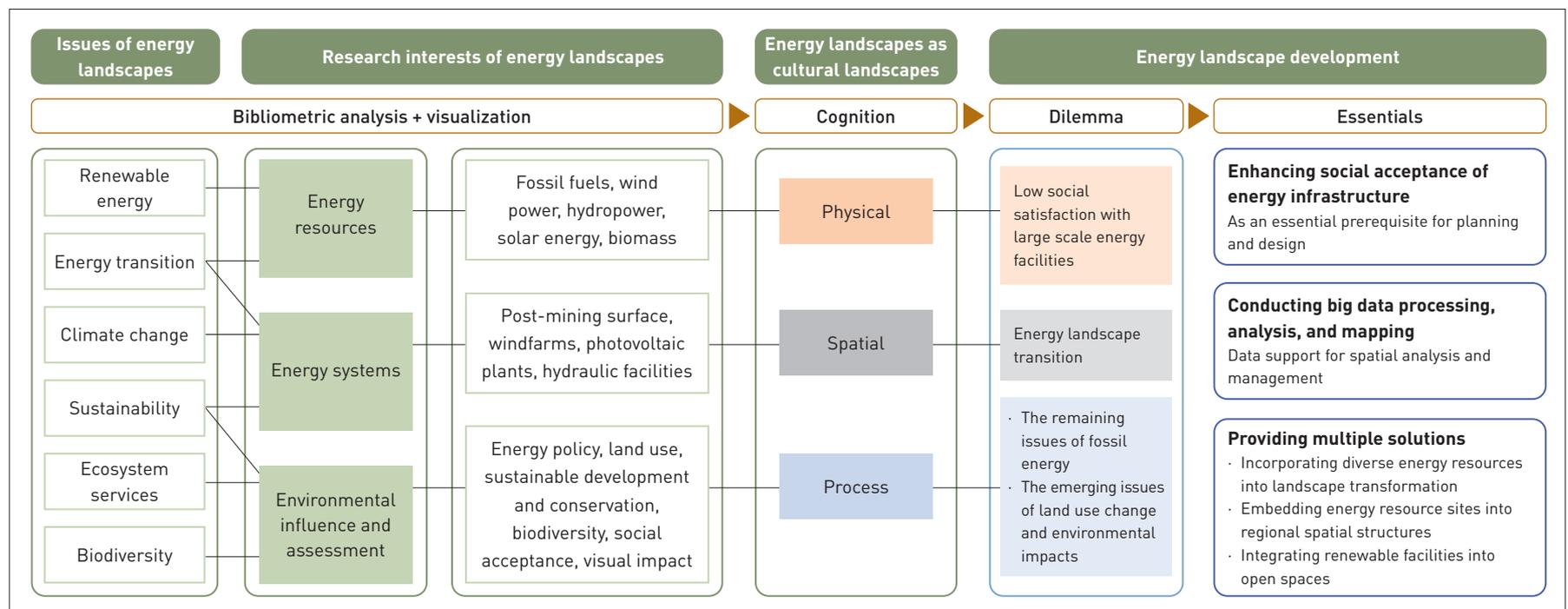
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## GRAPHICAL ABSTRACT



## ABSTRACT

In the 21st century, the increasing importance of renewable energy in addressing climate change and environmental sustainability has posed opportunities and challenges to the exploration of energy landscapes. A crucial question arises for disciplines related to spatial planning and design: how to theoretically and practically collaborate to appraise the meanings, classifications, and characteristics of energy landscapes, as well as their future development? Answering this question is essential for the discipline of Landscape Architecture to deepen the understanding of energy landscapes. Therefore, this research utilizes a scientific bibliometric

methodology, complemented by typical case studies, to review relevant literature and projects. This systematic approach aims to offer a comprehensive explanation of key issues about energy landscapes. Ultimately, three fundamental aspects for the future sustainable development of energy landscapes are identified: enhancing social acceptance of energy infrastructure; conducting big data processing, analysis, and mapping; and providing multiple solutions of planning and design. In conclusion, this research seeks to shed light on the significance, role, and potential of landscape in the energy transition for planners and designers.

## KEYWORDS

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Climate Change; Energy Transition; Renewable Energy; Energy Landscapes; Spatial Planning and Design

## HIGHLIGHTS

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- Offers a systematic overview of energy landscapes to encourage inter-regional and cross-cultural research
- Clarifies that energy landscapes are complex concepts in the dimension of cultural landscapes
- Identifies essentials of future sustainable development of energy landscapes at three key aspects

## RESEARCH FUNDS

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## 1 Introduction

The urgent need to expand the use of renewable energies, driven by the necessity to combat climate change and meet increasing energy demands amid dwindling fossil fuel reserves, poses unprecedented challenges<sup>[1]</sup>. The Paris Climate Change Conference (COP21) in 2015, after years of negotiations among 193 countries, marked a watershed moment in the burgeoning global emphasis on renewable energy<sup>[2]</sup>. The accelerated development of renewable energy, regarded as the most convenient, environment-friendly, dependable, and cost-effective means of realizing climate objectives, aligns with the United Nations (UN) Sustainable Development Goal 7 (SDG 7), which advocates for universal access to affordable and clean energy (e.g., wind, solar energy, and biomass)<sup>[3]</sup> in a manner that is equitable, methodical, and well-considered.

Accordingly, a “great transition” in global energy, including a “solar revolution” in the residential and commercial sectors, particularly prominent in North America, Italy, Germany, China, and Austria; alongside an “age of wind” unfolding notably in China, the UK, Italy, France, Canada, Denmark, Germany, and Portugal<sup>[4]</sup>.

Despite these advancements, the UN’s tracking report indicates that the proportion of renewable energy accounted for merely 19.1% of total final energy consumption in 2020—a marginal increase from 16% a decade prior<sup>[5]</sup>. To limit temperature increases below 1.5°C throughout this century, the share of renewables must reach 33% to 38% by 2030<sup>[5]</sup>. In response to this challenge, a critical accord to speed up the transition towards renewables was reached at the UN Climate Change Conference (COP28) in 2023, marking a significant step toward realizing the Paris Agreement’s goals.

The energy transition, driven by the climate crisis and its associated transformations, has become a global concern of mounting significance, which has promoted Landscape Architecture scholars to focus more on landscape transformations associated with energy extraction and utilization<sup>[6]</sup>. The construction of open-pit and underground coal mines, hydroelectric power plants, large wind farms, and photovoltaic (PV) stations all significantly alter the Earth’s surface, with substantial implications for ecosystem service provision<sup>[7][8]</sup>. The energy transition also necessitates the remediation and repurposing of brownfield sites, along with identifying suitable locations for modern renewable energy infrastructure. Concurrently, the appearance and location of energy landscapes, even those created by a single technology, can evoke divergent public perceptions, reactions, and policies<sup>[9]</sup>, posing significant challenges and essential tasks for landscape planning and design<sup>[10]</sup>. This research posits “landscape” as a systematic basis for understanding the typologies and processes in energy transition to explore the following two questions.

1) How to cultivate a systematic understanding of energy landscapes among diverse academics and practitioners, thereby encouraging more geographically focused discussions in the future?

2) How to thoroughly appraise the opportunities and trends arising from the development of renewable energy landscapes via typical case studies, to advance inter-regional and cross-cultural landscape understanding and collaboration?

## 2 Overview of Energy Landscapes

### 2.1 Cognition of Energy Landscapes

Energy landscapes emerge from the interplay of technological advancements, energy resource utilization, environmental shifts, and

social acceptance and recognition. Considering energy transition and its environmental impacts, English landscape architect Sylvia Crowe reflected complex energy infrastructure, particularly large-scale wind and solar installations, as “landscapes of power.” Crowe argued that “energy quests had destroyed [...] landscapes and left a legacy of thousands of acres of ugly and derelict land.”<sup>[11]</sup> However, they represent new forms of landscapes—from mining operations and power plants to coal transmission and electric lines—as energy infrastructure siting, zones of influence, and scale of energy lands change. Furthermore, in response to the changing relationship between energy, technology, and landscape, American scholar David Nye articulated the social construction of technology and suggested the new social and technological conditions for energy infrastructure through a sublime experience<sup>[12]</sup>.

During the 21st century, the term “energy landscapes” formally appeared in literature with the 2002 publication *Wind Power in View: Energy Landscapes in a Crowded World*, which describes the aesthetic impact of energy landscapes from a global perspective<sup>[13]</sup>. The lexicon of this domain comprises several variants such as “landscapes of energies”<sup>[14]</sup>, “regenerative energy landscapes,” “sustainable or renewable energy landscapes”<sup>[15]</sup>, and “energyscape”<sup>[16]</sup>, shaped by linguistic and cultural backgrounds. Increasingly, energy landscape is recognized as an interdisciplinary term<sup>[9]</sup> and research subject rooted in spatially-oriented disciplines, including Architecture, Spatial Planning, Urban Planning, and Landscape Architecture. It also integrates rich connotations of Economics, Sociology, and Ecology, and engages with multiple stakeholders, e.g., experts, investors, local decision-makers, energy consumers, communities, and neighbors<sup>[17]</sup>.

In Landscape Architecture, energy landscape represents the transformations in physical environments driven by energy demands<sup>[9]</sup>. As the extensive, long-term use of energy resources is ubiquity and global reach, energy landscapes transcend borders in this sense. Moreover, the concept of energy landscapes is evolving and multifaceted, including the connotation of energy resource, the “marks, structures, excavations, creations, and supplements that energy developments produce”<sup>[9]</sup>, and various influences on such as technologies, visual impacts, societal aspects, ecological effects, and policies. For example, scholars define the hybrid infrastructural landscapes of energy and mobility as “conduit urbanism”<sup>[18]</sup>. Therefore, the understanding of energy landscapes can be explored as cultural landscapes<sup>[6][9]</sup>, which are shaped by human activities and the interaction between human and nature<sup>[19]</sup>. For instance, the wind and solar installations of the Hamburg Energy Hill Project in Germany not only offer renewable energy to approximately 4,000

households across 8,500 m<sup>2</sup><sup>[20]</sup>, but also create a revitalized energy landscape through brownfield remediation and the integration with cultural landscape elements of the Wilhelmsburg area (e.g., the Elbe River, the A1 motorway, industrial buildings) (Fig. 1).

Given the above-mentioned review, energy landscapes in this research refer to a kind of cultural landscape shaped by human agency, which not only include energy resources and their physical manifestations, but also reflect the processes that transform the landscape. Energy landscapes serve as a medium to understand the society’s relations with resources in a region, enabling reflections on historic development, interpretations of the status quo, and prediction of the future. At the same time, they prompt critical question about how people can pursue energy development while conserving and reevaluating the values of the landscapes.

Despite the long-standing presence of energy landscapes in people’s daily lives, research on energy landscapes remains marginal in the field of Landscape Architecture. As Martin Pasqualetti and Sven Stremke revealed, energy landscapes are still “a fresh topic of academic and lay consideration,” according to the low literature statistics of a SCOPUS query<sup>[9]</sup>. This oversight might be attributed to apathy, or perhaps a sense of futility regarding the possibility of connecting the research interest in landscape studies with the need of energy development<sup>[21]</sup>.

Given the aforementioned information, there is a pressing need for in-depth and comprehensive analyses of energy landscapes in the context of climate change and energy transition. Thus, this research presents a systematic review of current advancements, which identifies the research hotspots, and the typologies and characteristics of energy landscapes, studies the built projects, and highlights the prevailing trends and emerging directions in planning and design. Crucially, a global perspective has the potential to not only foster a holistic understanding of energy landscapes and broader academic engagement, but also reveal



1. The Energy Hill Project in Germany, implemented by the International Building Exhibitions (IBA) Hamburg.

shared challenges and opportunities, supporting local actions and encouraging wider communication and cooperation.

## 2.2 Methods and Data Collection

To integrate theoretical research and practice, this research employed a two-pronged approach—combining a scientific bibliometric analysis and a qualitative typical case study. The bibliometric analysis utilized statistical mathematics and two scientific mapping tools (VOSviewer and GraphPad Prism) to explore domain-specific literature, discover the footprint of scientific research advancement, and predict future research hotspots in energy landscape<sup>[22]</sup>.

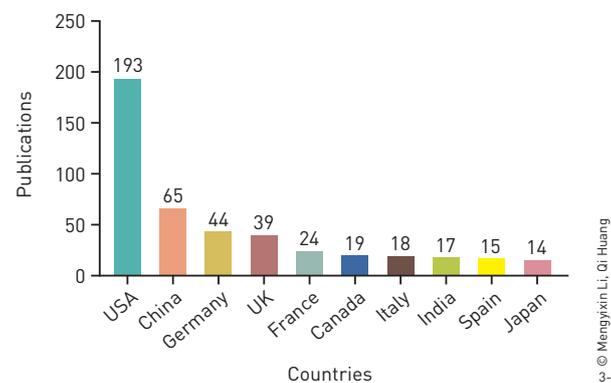
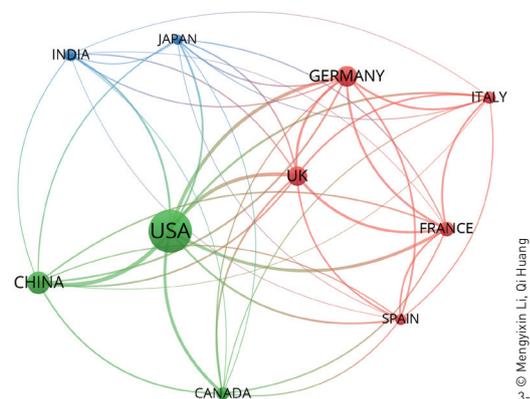
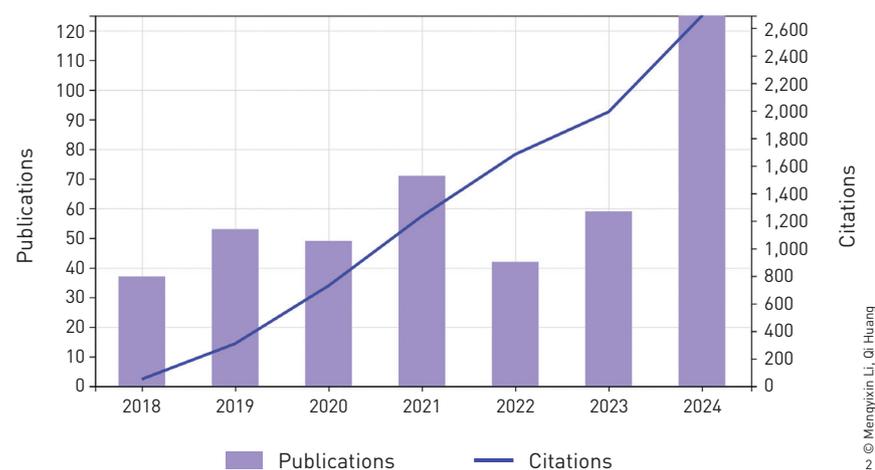
This research relied on the Web of Science (WoS) Core Collection database. The search was conducted with the keywords of “energy landscapes,” “landscapes of energies,” “regenerative energy landscapes,” “sustainable energy landscapes,” “renewable energy landscapes,” “energyscape,” and “landscape architecture,” spanning from 31 January 2018 to 31 December 2024, and obtained a total of 482 documents on 14 March 2025. The literature documents were then narrowed down to papers and review articles in English, finally with 436 valid documents kept for analysis after excluding irrelevant literature through manual reading of keywords and abstracts.

This research also conducted a typical case study to complement the bibliometric analysis. The cases were selected based on the obtained literature, and the authors’ knowledge and fieldwork experience about historic and present energy landscape projects. Utilizing uniform energy technologies under the influence of industrialization and globalization has led to a marked homogenization of energy landscapes. Thus, instead of listing a large number of similar cases, this research selected some influential and illustrative energy landscape projects with a rich literature base, clear design ideas, and high social acceptance. These energy landscape projects representing different development stages were analyzed to demonstrate the elements, characteristics, and potential of landscapes for various energy typologies across geographical and cultural contexts.

## 2.3 Bibliometric Results and Visualized Analyses

From 2018 to 2024, the number of published research related to energy landscape exhibited a fluctuating trend, while the number of citations over time kept increasing (Fig. 2). This suggests a growing interest in energy landscapes in academia. Specifically, the top five countries in terms of scientific publications and research collaboration on energy landscapes are the United States of America

(USA), China, Germany, the UK, and France (Fig. 3). Obviously, the USA has a far greater number of publications than any other country, probably because it has predominant collaborative links with others (seen from the size of the node) in international networks. In addition, Fig. 3 indicates that inter-regional collaboration network among the top ten countries consists of three clusters, namely five European countries (red), North America and China (green), and Japan and India (blue), reflecting that they share similar themes. Recently, the research papers across nearly all countries hypothesize that the dawn of the Renewable Energy Age will fundamentally reshape the landscapes where people inhabit.



1. Number of publications and citations of energy landscape related research (2018 ~ 2024).
2. Number of publications and citations of energy landscape related research (2018 ~ 2024).
3. Top ten countries of energy landscape-related research publication, and inter-regional collaboration network (2018 ~ 2024).



**Table 1: Characteristics and typical cases of energy landscape typologies**

Energy landscape typology	Energy source	Energy facility	Characteristic	Typical case	Source
Historical energy landscapes	<ul style="list-style-type: none"> <li>Hydropower</li> <li>Wind power</li> </ul>	<ul style="list-style-type: none"> <li>Watermill</li> <li>Windmill</li> </ul>	Architectural style, locality, everyday space, historical and cultural features	<ul style="list-style-type: none"> <li>Windmills of Kinderdijk, the Netherlands</li> <li>Windmills of Consuegra, Spain</li> <li>Water Management System of Augsburg, Germany</li> </ul>	Refs. [7][38][39]
Fossil energy landscapes	Fossil fuel	<ul style="list-style-type: none"> <li>Mega steel equipment for coal mining</li> <li>Energy transportation network</li> </ul>	Geological, large-scale, permanent change	<ul style="list-style-type: none"> <li>IBA Fürst-Pückler-Land in Lusatia, Germany</li> <li>Blaenavon Industrial Landscape, the UK</li> <li>The Lewarde Mining History Centre, France</li> <li>Mining Basins of Castile and Leon, Spain</li> <li>Pan'an Lake Wetland Park (coal mining subsidence area), China</li> </ul>	Refs. [40]~[44]
Renewable energy landscapes	<ul style="list-style-type: none"> <li>Hydropower</li> <li>Wind power</li> <li>Solar energy</li> <li>Biomass</li> </ul>	<ul style="list-style-type: none"> <li>PV and concentrated solar power (CSP) array</li> <li>Huge industrial-scale wind turbine</li> <li>Hydraulic facility along river</li> <li>Scattered biomass system</li> </ul>	Globalization and standardization, repeatability, regularity, life-cycle	<ul style="list-style-type: none"> <li>Energieberg Georgswerder, Germany</li> <li>Solarpark de Kwekerij, the Netherlands</li> <li>Gemasolar Thermosolar Plant, Spain</li> <li>Wind Energy Landscape in Brandenburg, Germany</li> <li>Glen Canyon Dam, the USA</li> <li>Potential of PV and biomass fields in eastern Ontario, Canada</li> <li>Three Gorges Dam, China</li> </ul>	Refs. [20][33][45]~[49]

handicraft periods (1500 ~ 1800)<sup>[7]</sup>. Watermills, for instance, do not require strong water flow—even small streams could power the structures. Primarily utilized for grinding staple foods (e.g., grains), the watermills were closely associated with people's daily lives<sup>[35]</sup>. Over time, many surviving watermills have been preserved as historical landmarks, forming picturesque landscapes with the nearby streams and pathways<sup>[50]</sup>.

In the global tourism industry, windmills stand as an icon of the Dutch cultural landscape, among which the most renowned are the windmills of Kinderdijk, a designated UNESCO World Heritage Site (Fig. 5). The protection efforts have extended beyond the windmills to encompass the surrounding polder landscape and the village in which they are situated<sup>[50]</sup>. A similarly iconic windmill landscape can be found in Consuegra, Spain, which is widely recognized for being mentioned in a famous novel.

Watermills and windmills are intrinsically tied to their surroundings, built using local materials, construction techniques, and architectural styles. Their proportions align harmoniously with other structures from the same historical period. The romanticized image of these energy landscapes has been molded by a convergence of influences, including literature, paintings,

contemporary imagery on social media and various other communication channels<sup>[51]</sup>. This type of energy landscape has earned recognition as a vital element in historic cultural landscapes.

### 3.2 Fossil Energy Landscapes

The Industrial Revolution represents the rise of mechanized mass production and mechanical infrastructure, primarily composed of steel, which was the main carrier for energy landscapes of the time. For instance, coal mining operations require not only heavy industrial machinery and facilities but also various

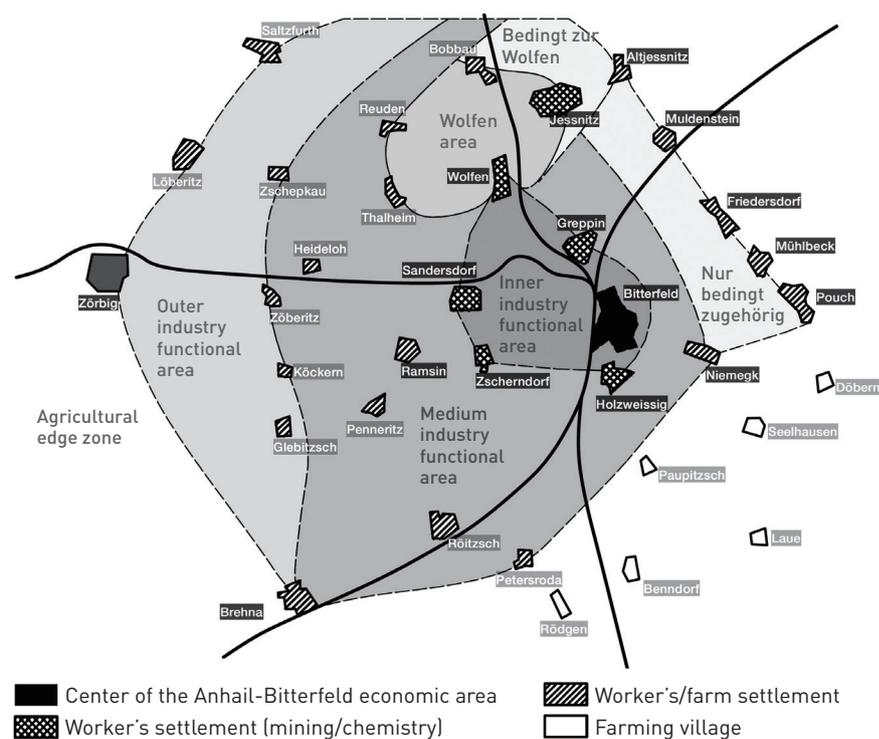


5. The windmills of Kinderdijk as an icon of the historic cultural landscape.

supporting infrastructure, including the workers' housing, extensive rail networks, temporary storage sites at river or seaports, and artificial slag heaps. As these facilities are being abandoned as energy transition proceeds, they come to represent a regional post-industrial landscape. For example, in Blaenavon region of the UK, the mining features merge with the surrounding valley landscapes, which has been designated as a UNESCO World Heritage Site. In Lusatia and Anhalt-Bitterfeld regions (Fig. 6) of Germany, opencast brown coal mining has sculpted the landscape with a lunar-like appearance<sup>[52][53]</sup>. As part of the IBA initiative<sup>①[54]</sup>, the disused coal mines in Lusatia region are being revitalized into artificial lakes for public recreation. The effect of this energy landscape extends beyond the limits of a single city or village, shaping a broader regional character<sup>[55]</sup>.

The geographic distribution of non-renewable resources (e.g., peat, coal, oil) determines the sitting and the main influencing areas of the fossil energy landscapes<sup>[56]~[58]</sup>, such as the Cantabrian region in Spain, the Ruhr area in Germany, and the Lewarde Mining History Centre (LMHC) in France. These areas have experienced economic decline and population loss following the reduction or

① International Building Exhibitions (IBA): A special format of urban and regional development, and experimental fields for exploring complex social, economic, ecological, aesthetic, and technological issues, created on the initiative of the German Federal Government [source: Ref. [54]].



6. Structural analysis of mining industrial landscapes in Anhalt-Bitterfeld region, Germany (student project from LAREG Project Studio).
7. Prevalent types of renewable energy landscapes.

cessation of coal extraction. While the value of the fossil energy landscapes is acknowledged, they have not garnered the same level of public appreciation as natural landscapes or a type of cultural landscapes<sup>[42][59]</sup>. This underscores a pressing need for comprehensive ecological restoration and design strategies for the fossil energy landscapes.

### 3.3 Renewable Energy Landscapes

Unlike fossil fuels which are limited by geographic distribution, renewable energy resources are more available worldwide, offering greater flexibility in site selection and installation<sup>[60]</sup>. Among various renewables, wind and solar energy represent the two most prevalent types<sup>[61]</sup>, which are the focus of this section. However, the proliferation of standardized PV modules and wind turbines has led to a globalized and increasingly homogeneous and fragmented energy landscape<sup>[62][63]</sup> (Fig. 7).

The topography of a wind farm site significantly influences its spatial layout<sup>[6]</sup>: on rolling hills, wind turbines often follow irregular, curved alignments with maintenance roads; whereas on plains or shorelines, they typically appear in a regular array and evenly distribution. To optimize energy output, the height of the wind turbines have increased to over 200 m<sup>[6]</sup>. This scale contrasts sharply with other natural or built landscape elements (e.g., trees or houses) (Fig. 8), defining a distinctive type of energy landscape. Due to their high visibility, wind turbines have raised concerns



8. Contrasts created by individual large wind turbines with other landscape elements.

and debates regarding their impacts on natural landscapes<sup>[64]~[66]</sup>, particularly those known for the scenic beauty, such as the Alps. Accordingly, land use planning often prioritizes the wind turbine deployment in regions designated as having “low landscape value.”<sup>[61][67]</sup> However, this approach risks exacerbating existing inequalities in landscape development and quality of living areas between different regions, potentially causing landscape injustice<sup>[67]</sup>.

PV technology represents the prevalent application of solar energy today. Starting in the 1990s, initiatives such as the 1,000-Roofs-Programme in Germany<sup>[6]</sup> steadily promoted the adoption of PV technology among homeowners. Driven by a desire to make buildings more energy-efficient, early adopters in the field of architecture embraced the use of PV facilities, taking justifiable pride in this approach (building-integrated PVs)<sup>[68]</sup>. Since 2010, there has been a significant growth in solar energy application, particularly the ground-mounted and floating PV power plants<sup>[69][70]</sup>, which was fueled by declining costs of polycrystalline and monocrystalline silicon PV modules<sup>[71]</sup>. PV facilities are generally installed in rural areas, cropland, woodlands, and grassland<sup>[72]</sup>. Compared with wind farms, PV plants tend to be less visually intrusive and have a higher acceptance by communities<sup>[73][74]</sup>. PV arrays are typically arranged in highly regular, repetitive layouts, resembling the circuit diagrams<sup>[75]</sup>. To enhance land use efficiency, multifunctional land use for PV facilities are prevalent, such as agricultural PVs and floating PVs<sup>[76][77]</sup>, thus becoming integral components of rural landscapes. However, large-scale solar power stations located in confined areas can create imposing landscape features, potentially disrupting ecological corridors or occupying spaces for daily activities of local residents<sup>[78][79]</sup>.

## 4 Essentials of Energy Landscape Development

The typology and characteristic review of energy landscapes in different periods reveals issues. First, the acceptance and

satisfaction with historical energy landscapes are relatively high, but large-scale energy facilities are not perceived as part of the landscape aesthetics. Thus, gaining social acceptance for renewable energy landscapes becomes the key for their development<sup>[6][65]</sup>. Second, the ongoing energy transition presents a dual challenge—addressing the problems caused by using traditional fossil energy resources, while responding to new concerns with renewables in the context of climate change, including land use conflicts, environmental impacts, and the application of advanced technologies in large-scale landscape planning and design.

In light of these challenges, this research proposes an exploratory path toward the future sustainable development of energy landscapes with three strategies. First, enhancing social acceptance of energy infrastructure as an essential premise to address land-use constraints and energy transition obstacles. Second, conducting multi-layered spatial data processing, analysis, and mapping to support energy landscape development, while addressing the mutual influences between energy systems and their potentials, land uses and topography. Third, providing multiple solutions for energy landscape development through cross-regional and interdisciplinary research and collaboration.

### 4.1 Enhancing Social Acceptance of Energy Infrastructure

The deployment of renewable energy infrastructure affects not only physical landscapes but also the residents and communities in adjacent areas<sup>[80]</sup>, which raises a crucial challenge for landscape architects: how to understand and reconcile the relationship between people, energy infrastructure development, and landscape conservation? Wind and solar energy projects are prominent examples where fostering social acceptance is essential. Importantly, studies indicate that local resistance to these projects is not merely a reflection of a “not in my backyard” mentality. Furthermore, it often stems from a failure to adequately consider socio-cultural dimensions during the planning phase<sup>[81]</sup>. In addition, “non-acceptance,” “opposition,” or “resistance” against wind and solar energy facilities are frequently evaluated. Findings suggest that such negative reactions are commonly attributed to several aspects, including encroachment upon the landscape, a lack of trust, concerns related to social justice, and anxieties regarding the damage to the environment and local image<sup>[82][83]</sup>.

Moreover, public responses to renewable energy facilities are inherently complex and shaped by socio-cultural factors. They vary across countries, locations, technologies, policies,

and demographic characteristics (e.g., age, education level, and familiarity with a given energy source)<sup>[6][22][65]</sup>. For instance, Christiane Bohn and Christopher Lant found that community acceptance of wind energy projects in the USA often hinges upon the perceived procedural legitimacy of siting decisions and the aesthetic coherence between the project and local landscape<sup>[84]</sup>. Reflecting on the robust critical awareness and commitment to public engagement in German society, Sören Schöbel pointed out that the considerations of social acceptability should extend beyond the functional and rational dimensions of energy infrastructure to include the spatial relationships with surrounding environmental elements and aesthetic qualities embedded in energy infrastructure<sup>[6]</sup>. Ultimately, social acceptance must be integrated across all stages of a project—from preliminary analyses to planning and design.

#### 4.2 Conducting Big Data Processing, Analysis, and Mapping of Energy Landscapes

The development of future energy landscapes relies heavily on spatial data analysis and mapping<sup>[60]</sup>. Given the extensive reach of modern energy infrastructure, planning and design must extend beyond urban boundaries to coordinate with the goals of nature and landscape conservation and historical structure preservation<sup>[85]</sup>.

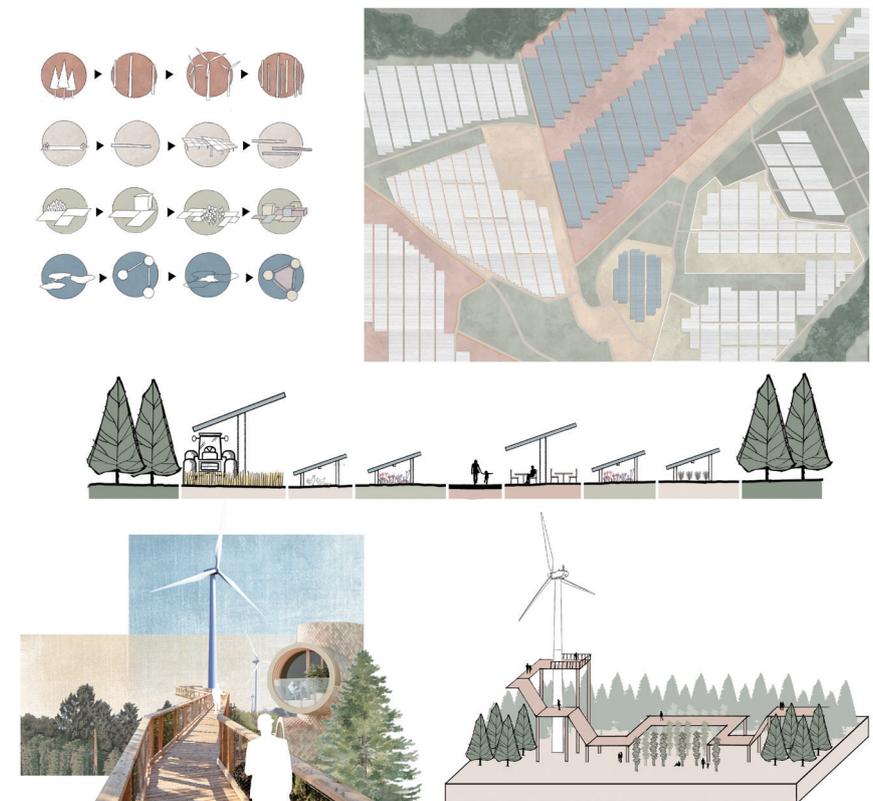
Therefore, it is essential to conduct comprehensive analysis of existing energy systems and mapping of renewable energy potential. This demands multidisciplinary collaboration among planners, designers, energy specialists, and local experts. During the process, GIS-based operations play a critical role in data integration, spatial analysis, landscape change and characteristic monitoring, and future trend forecasting<sup>[86]~[88]</sup>. Although there has not emerged a standardized methodology for managing land use data and coordinating the complex factors for energy landscape development, experts and scholars have explored spatial analysis through digital geomorphic modelling, scenario modelling, conflict risk assessment, and multi-scale impact factor visualization. For instance, Stremke established the energy landscape data system and demonstrated potential long-term development networks in South Limburg, the Netherlands<sup>[89]</sup>. Similarly, Adrienne Grêt-Regamey and Ulrike Wissen Hayek mapped potential areas of renewable energy in Entlebuch, Switzerland, highlighting its capacity for providing ecosystem service<sup>[8]</sup>. In Bavaria, Germany, a visual map illustrating potential areas for wind, solar, hydropower, and biomass energy has served as a valuable tool to support stakeholder discussion and decision-making<sup>[6]</sup>.

#### 4.3 Providing Multiple Solutions for Energy Landscape Development

On the basis of enhancing social acceptance and multi-layered data support, bringing in planning and design approaches can provide multiple solutions for energy landscape development—incorporating diverse energy resources into landscape transformation, embedding energy resource sites into regional spatial structures, and integrating renewable facilities into open spaces. Taking the Lausitz region in Germany as an example, the areas historically dominated by fossil energy extraction are reimagined for renewable energy generation (Fig. 9). In the meantime of the brownfield remediation, it is needed to select suitable sites for wind and solar power facilities<sup>[90][91]</sup> accompanied by planning and design that takes both the characteristics of wind and solar energy resources into account<sup>[92]</sup>, deploying wind and solar power facilities together and identifying suitable sites to complement intermittency<sup>[90][91]</sup>, thereby increasing the reliability of energy provision<sup>[93]</sup>.

Moreover, to avoid potential landscape injustice caused by existing land use policies<sup>[67]</sup>, it is crucial to recognize the potential of energy landscapes not only as infrastructure zones but also as recreational spaces for the general public, enhancing the quality of life for nearby

9. Design concept for energy landscapes in Lausitz region in Germany (student project from LAREG Project Studio).



residents. Consequently, simply allocating large peripheral zones for renewable energy facilities is no longer sufficient. Multiple solutions that include renewable energy facilities in urban and rural fabric are imperative during urban landscape planning and design<sup>[94]</sup>.

In parallel with advances in energy-efficient architecture showcased at world expositions in recent years, there has been a growing emphasis on integrating renewable energy facilities (e.g., PV cells) into open spaces. Terra—The Sustainability Pavilion at EXPO 2020 Dubai, designed by Grimshaw Architects<sup>[95]</sup>, represents this approach. Similarly in the new headquarters of the Swatch in Biel, Switzerland, 1,770 m<sup>2</sup> of PV panels have been integrated into the building structure, harmonizing with the Schüssinsel Park and the hilly landscape (Fig. 10). Learning from these classic BIPV solutions, applying more renewable energy facilities in open spaces with design methods can expand the utilization of renewables, especially in high-density urban areas.

## 5 Conclusions and Prospects

The urgency of addressing climate change and the depletion of fossil fuel reserves call for an unprecedented transformation of the built environment toward one that prioritizes sustainability, robustness, and resilience. Therefore, the future of energy landscapes has emerged as a critical global concern, demanding comprehensive and multidisciplinary investigation. The network distribution of diverse renewables across expansive geographical backgrounds has given rise to a new frontier at the intersection of Landscape Architecture and energy sector. The significance of this growing field has been highlighted by the longstanding historical interplay of energy utilization and spatial organization, particularly the mutual influence between energy production and partial design principles<sup>[96]</sup>.

In response to the emerging challenges and opportunities in global energy landscapes, this research employs a methodological framework including quantitative literature reviews and typical case studies, evaluating research hotspots, typologies, and characteristics of energy landscapes, thereby proposing essentials for future development. The findings contribute a research panorama in the field of Landscape Architecture, effectively laying a foundation for further theoretical enrichment and practical advancements. Meanwhile, this research anticipates the following prospects for future exploration.

1) Disciplines related to spatial planning and design are uniquely positioned to spearhead the conceptualization of future energy landscapes, offering sustainable, long-term solutions



10. Schüssinsel Park and the new headquarters of the Swatch in Biel, Switzerland.

that harmoniously integrate ecological, economic, and socio-cultural dimensions. This highlights the need to elevate the role of landscape architects in cultivating cross-disciplinary dialogue and collaboration, particularly in light of the transformative opportunities presented by the ongoing energy transition and spatial environment reorganization.

2) As global population continues to rise, understanding and shaping energy landscape through a broader lens of cultural landscape and diverse perspectives is necessary. Energy landscapes are emerging as a critical and distinct category in landscape conservation and territorial development.

3) In the context of spatial planning and design, energy landscapes should respond to their connections with multiple domains and confronting a broad spectrum of challenges, including climate change, ecosystem services, landscape conservation, brownfield revitalization, landscape equity, spatial quality and perception, regional spatial development, and tourism economics. Addressing these issues will imbue energy landscapes with evolving connotations, functionalities, and values.

In conclusion, future energy landscapes are expected to not only adapt to, but also actively shape the transformations occurring across global, regional, and local scales, cultivating more positive outcomes. For landscape architects, this signifies a call to action—a necessity to embrace the tasks, opportunities, and challenges in all aspects of society and culture, ecology, economy, policy, etc.

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# 能源景观综述：认知、类型与发展

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## 摘要

21世纪, 可再生能源在应对气候变化和环境可持续性方面愈发重要, 这为能源景观探索带来了诸多机遇和挑战。与空间规划设计相关的各个学科也正面临着一个重要问题, 即如何从理论和实践层面评定能源景观的内涵、分类、特征及其未来发展。在景观设计学领域, 对这一问题的解析已成为加深对能源景观理解的关键。基于此, 本研究采用科学的文献计量学方法, 辅以典型案例研究, 对相关文献和实践项目进行了系统性梳理, 旨在全面阐释能源景观所涉及的关键性议题。最终, 本研究明确了实现能源景观未来可持续发展的三项基本内容, 即提升能源基础设施的社会接受度, 开展大数据处理、分析和制图工作, 以及在规划设计中提供多种解决方案, 以帮助规划和设计工作者了解景观在能源转型中的意义、作用和潜力。

## 关键词

气候变化; 能源转型; 可再生能源; 能源景观; 空间规划与设计

## 文章亮点

- 对能源景观展开系统性概述, 以鼓励跨地区及跨文化研究
- 阐明了能源景观是文化景观层面的一个复杂概念
- 从三个关键方面明确了能源景观的未来可持续发展要点

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