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Energy landscapes in a crowded world: A first typology of origins and expressions

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ABSTRACT

One of the main drivers of landscape transformation has been our demand for energy. We refer to the results of such transformations as "energy landscapes". This paper examines the definition of energy landscapes within a conceptual framework, proposes a classification of energy landscapes, and describes the key characteristics of energy landscapes that help to define an over-arching typology of origins and expressions. Our purpose is to inform scholarly discourse and practice with regard to energy policies, decision-making processes, legal frameworks and environmental designs. We exam the existing literature, provide a critical perspective using imagery from the USA and Europe, and combine the disciplinary perspectives of geography and landscape architecture. We propose three main characteristics that contribute to the development of a typology: (1) *Substantive qualification*: General types of energy landscapes distinguished by dominating energy source; (2) *Spatial qualification*: The appearance of energy landscapes, ranging from distinct spatial entities to less recognizable subsystems of the larger environment; and (3) *Temporal qualification*: The degree of permanence of energy landscape ranging from relatively dynamic to permanent. Addressing these and a growing number of associated questions will promote more thoughtful protection of the landscapes we inherit while paying closer attention to the relationships between ourselves and the landscapes that surround us.

1. Introduction

Imagine living in a time before internet, mobile phones, televisions, radios, books, town criers, or sophisticated language. Everything you needed to know – or could know – would come from reading the landscapes that surrounded you. It would be a relational experience; you would learn the give and take of the landscape. Using all your senses all the time, you would be acutely alert for any changes in appearance, process, opportunities, and threats. Vision would be indispensable, but you would also feel the earth under your feet, taste flavors the landscape offered, smell odors wafting over the landscape, and hear – perhaps with some trepidation – the jabberings of wild animals that were sharing the landscape with you.[1] Over time, you would sharpen your skills at reading landscapes, become attentive to the stories they had to tell, and be constantly alert for any hint or clue they might provide that would prove valuable to your personal safety and well-being.

Looking back, we see that relationships between society and landscapes have evolved. For most of our time on planet Earth, we worried about the dangers landscapes embodied. By the beginning of the 20th century, however, we were beginning to reverse course. Instead of fearing landscapes, we had started embracing them, including untamed ones, for their values, including aesthetic qualities they held, such as solitude. Henry David Thoreau best expressed this redirection when he declared: "In wildness is the preservation of the world" [1]. Eventually we completed the readjustment in our relationship to landscapes from one of fear to one of appreciation. We came to consider many of them "jewels" that needed our protection and merited our safe keeping. We began realizing that as we strived to save landscapes, we were striving to save ourselves.

Thoreau counseled us to resist taking landscapes for granted, to avoid fastening ourselves to the false promise of landscape permanence that often springs from our relatively short human lifespan. Notwithstanding his advice and despite the agreed value of landscapes – in appearance as well as function – we seem seldom able to leave them undisturbed. Living with more than 7 billion neighbors underscores the strain of consistently supporting landscape

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[1] Paraphrased and amended from thoughts by Anne Whiston Spirn. The language of landscape, Yale University Press, 1998.

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sovereignty, independence and longevity. Instead, we continue meddling, regularly manipulating landscape shapes, purpose, manner and intensity, creating what geographers often refer to as "cultural landscapes", that is, the natural environment as influenced by human agency. Often the creation of these cultural landscapes results from commissioning energy resources to sustain human life. In recent years, many observers have started referring to the visible results of the unending and insatiable human quest for Nature's most fundamental resource. We call these 'energy landscapes'.

Over the centuries, energy landscapes have assumed many forms, but for most of that time the alterations and even damage that they produced were seldom linked directly to the growth of energy demand. We were poor at making the linkages between our need for energy and the landscape consequences that resulted. These costs were usually given the innocuous label of 'collateral damage'. They were seen as unavoidable environmental costs that, in earlier less-crowded times, would simply be left behind as we carved up virgin territory.

Many energy landscapes accumulated in remote regions, far from population centers and probing skepticism. They were out of sight and out of mind, and one did not recognize the common thread of their origin or the possible measures that could help to mitigate the consequences of their presence. Today, with an increasing ubiquity, there is rising interest in focusing attention on them as a unified topic. Energy landscapes are co-constructions of space and society that come into existence through a series of material and social relations. They have been accumulating to such a degree in recent years that they no longer can elude our recognition and concern [2].

Now that we have become alerted to the signatures of energy landscapes, we tend to spot them everywhere, in an exquisite variety of forms. We see them as scars left from mining, patchworks of drilling pads, cleared routes for pipelines and canals, harbors for large tankers, oil refineries, gas compression plants, generating stations, transmission lines, waste tips, fields of derelict equipment, arrays of solar panels, abandoned towns, and the exoskeletal forests of spinning turbines churning electricity from the wind.

The appearance, location, and recognition of energy landscapes incites wide swings of perceptions, reactions and policies, even when created by a single technology. For example, while some people may loathe wind turbines, others may consider the very same machines an attention-grabbing backdrop for their marital vows, such as has occurred in Palm Springs, California. Some people decry the wholesale destruction produced by mountain-top removal, while others see the resulting scars as visible evidence of valuable jobs and vital economic development.

In sum, the breadth of reactions to energy landscapes tends to place curves and bumps in the path to a sustainable future. The goal of this paper is to help straighten and smooth that path by developing a suitably reflective typology of energy landscape origins and expression as an introduction to a newly-recognized research domain.

We begin in Section 2 by laying a foundation for the proposed typology by summarizing the rising recognition of energy landscapes in the literature. The theoretical basis for the typological study of energy landscapes is laid out in Section 3. Section 4 advances the conceptual framework for the typology. These sections are followed by a discussion and conclusions. We combine the disciplinary perspectives of geography and landscape architecture to emphasize past and existing energy landscapes as well as the planning and designing of future energy landscapes. To illustrate the critical perspectives that are important to any understanding of energy landscapes, we incorporate a generous sampling of images from the United States and several countries in Europe, where such landscapes have been receiving the most scholarly attention.

2. The growing awareness of energy landscapes

Energy landscapes are found in myriad forms and locations, some expected and some exceptional. While one may expect to encounter them in such coal-rich places as the Cumberland Plateau in Kentucky, the Ruhr region in Germany, or the Midlands of England, they are starting to proliferate elsewhere as well. These may be places of scenic or historic value, along unspoiled ridgelines, astride busy highways, or even in the shallow waters off cherished beaches. Their growing profusion has been attracting increasing public attention, although this newfound awareness rarely partners with insight into how to make them smaller, less noticeable, or more acceptable.

It will become increasingly difficult – if not impossible – to meet global energy needs without creating new energy landscapes. Such landscape shifts may be a difficult reality to accept, especially wherever people would prefer that landscapes remain unchanged indefinitely. The increasing abundance of energy landscapes gives testimony to the fact that landscape permanence, a common human wish, is a myth leading to enduring disappointment. The advice of Thomas Wolfe – you can't go home again – never rang truer [3].

Many difficulties can surface as societies work to meet energy demands while simultaneously trying to limit the landscape effects that energy developments produce. A principal challenge is adjusting to the fact that the landscape impacts from energy developments differ spatially, by resource and geography, by public perception, and by conditions of life such as poverty, cultural constraints, and levels of opportunity. In Europe the creation of energy landscapes that we encounter today is part of a centuries-old progression. Germans can experience the spatial consequences of energy development by visiting the regions of Essen, Cologne, and Leipzig. In the Czech Republic, egregious examples of energy landscapes include the area surrounding the city of Most (Fig. 1) [4]. It has been in places such as these that the public has learned about environmental and financial costs that accompany energy development, how the scale and disruption of landscapes limit options for future use, and how difficult is the remediation that society might desire. Moreover, in densely populated Europe, energy landscapes are in view of millions of people. They cannot be avoided.

It is not uncommon for people in energy-rich areas to become habituated to energy landscapes from mining and related extractive activities. Either they are not bothered them, they consider it counterproductive to complain, or they accept them as a 'necessary evil' that trail the creation of jobs. Ironically, the flat trajectory of opposition to many traditional energy landscapes took a sharp upward turn with the growth of renewable resources such as wind power. This reaction was especially noticeable in California, the Netherlands, the UK and other places as early as the 1980s, where wind turbines were characterized as spinning, glinting, bird-chopping, noisy impositions on the land. They were in plain and obvious view, they could not be relocated or camouflaged, and many people detested them. It was a conflict of geographical incompatibility that owed its intensity to the site-specific nature of wind power itself [5]. In the UK, with a population density 8 times that of the United States, it immediately became difficult to find sites for wind turbines that were not in someone's field of view. The problem arose in California as well, albeit with different underpinnings. There the problem stemmed from the fact that two of the earliest sites for large-scale wind installations were co-located athwart the right-of-way of major highways heading toward the large metropolitan regions of San Francisco and Los Angeles. These energy landscapes became a fact of daily life for those who commuted along these roads. They could not be ignored.

Fig. 1. Surface lignite mine near the city of Most, Czech Republic. 2012. Such large scars have been particularly common in the Czech Republic, Germany, Poland, and many other central and eastern European countries. (Photo by M. Pasqualetti).

Although public awareness of the environmental consequences and associated societal hardships of energy landscapes grew rapidly over the last few decades, they are not new. Rather, they are just more frequently acknowledged and less frequently tolerated. Over the centuries, they took on a wide variety of forms, threats, and configurations along every stage of the energy chain, from exploration to waste disposal. Today, some are considered hazardous, others benign. Some temporary, others timeless. Some dispersed, others concentrated. Some active, some legacy. Some energy landscapes are renovated and reused while others are left untended for years in idle decay. Regardless of their shape, size, distribution, or form, all energy landscapes are now part of the public discourse about what we are willing to accept in exchange for the energy we want and need.

The attention they now attract does not stem solely from their 'physicality'. Other factors are also in play, many of them unique to the types of resources considered. These factors include the growing competition for land that is resulting from growing populations, increased opportunity and freedom for public participation in siting decisions, and speedier global communications. In addition, two additional innate characteristics of renewable resources stand out: low energy density and site-specificity. The first drawback translates into larger land requirements, such as solar power, geothermal and wind.[2] The second drawback further limits siting options, as with geothermal and wind developments.

As population continues to grow and expand, and as societal concern about environmental degradation continues its upward trend, there is growing realization that the days are long past when one can (or should) adjust to energy landscapes by ignoring them or restricting them to places where they are less likely to be encountered. People are becoming aware that there is no escaping the impacts of the energy they use – even as they are desperate for the benefits such energy provides. There is growing recognition that – as with clean air and water – the quality of the landscape cannot be taken for granted in the development of energy resources, although we recognize it is critical to our healthy and sustained existence. Such a rise in awareness is increasingly entering the public discourse, as manifested in the greater attention to energy landscapes found in scholarly articles (Fig. 2) [6], books [7], conferences [8] and the creation of academic research groups focusing on energy landscapes.[3]

3. Theoretical basis of energy landscapes

While it is beyond the scope and purpose of this paper to evaluate, analyze, and dismember the full spectrum of meanings attached to the elastic term "landscape", a brief discussion of its applications and connotations will help explain the recent addition of the word "energy" as a modifier. After all, the word landscape "…is over 300 years old and was drawn up for artists, who considered a landscape is a portion of land which the eye can comprehend at a glance" [9]. The meaning of the word has broadened considerably since then, often adapted in metaphorical connotation, such as when we refer to the "political landscape", or the "literary landscape". In this paper, however, we focus our attention on what is often referred to as the "cultural landscape", that is, on physical landscapes modified by human agency as incorporated into the research and application of numerous landscape architects and geographers [10]. It is within this context that Marc Antrop reminds us of the importance of understanding relations between landscape and people: "the processes and management in past traditional landscapes and the manifold relations people have towards the perceivable environment and the symbolic meaning it generates, offer valuable knowledge for more sustainable planning and management for future landscapes" [11]. The acceptance of this thematic emphasis was reflected recently at the European Landscape Convention (ELC). The ELC settled on this definition for the word landscape: "[…] an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors." The notion of "energy" landscapes, then, derives from this same sense, given that all

[2] It should be noted that the total land costs must be summed from a consideration of complete energy fuel chains. Pasqualetti, M.J., and Miller, B.A. Land requirements for the solar and coal options. Geographical Journal (1984): 192–212.

[3] Energy landscape chair at Versailles University, France as well as at the Amsterdam University of Arts, Netherlands; also there are dedicated research laboratories such as the NRGlab in The Netherlands (website: http://www.nrglab.net/, Accessed 16 September, 2017).

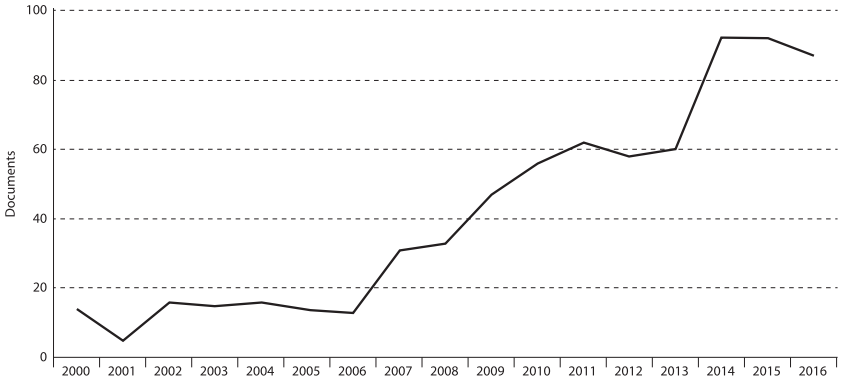

Fig. 2. SCOPUS query "energy landscape" and "social sciences" revealing an increasing number of scholarly articles since 2000.

Fig. 3. Abandoned coalmine that has been redesigned to serve recreational purposes connecting to the local history of this energy landscape near Bitterfeld-Wolfen in Germany (Photo by D. Stremke, 2007).

the energy landscapes addressed in this paper are produced by people.

The study of energy landscapes falls within the realm Leo Marx highlighted in *Machines in the Garden*, where his emphasis was to highlight the juxtaposition of technology and nature in our increasingly crowded world [12]. It was a theme that carried on in the work of others, notably Robert Thayer in his *Gray World, Green Heart*, and to a substantial extent, the work of David Nye, in his *American Technological Sublime* [13]. Yet, despite such attention, the earliest use of the phrase "energy landscape' did not appear in a book title until 2002 when Pasqualetti, Gipe and Righter published *Wind Power in View: Energy Landscapes in a Crowded World.*[4] The field of study has grown substantially in recent years – as discussed just below – yet there remains the challenge of establishing it as a well-delimited and unified topic of study. Summarizing, as it does, the features and adjustments encompassed by the label, we consider such refinement a principal goal of this paper.

Such refinement requires formalizing the study of energy landscapes in a way that explicates its genesis, public reactions, and the future of landscape reconfigurations that continue proliferating across our field of view. In result, this should help explain the challenges and limits of integrating energy landscapes into the fabric of our living environment. Hopefully, this contribution will have implications for research, teaching, policy formation, practice and governance, as well as spatial planning and landscape design as we transition from conventional energy sources towards renewables.

Combining 'energy' with "landscape" produces a useful unifying label for the marks, structures, excavations, creations, and supplements that energy developments produce. Taken together, this brand captures all the principal elements that appear at the confluence of energy and technology – i.e. technical, visual, social, ecological and political – making it an appealing identifier of a discreet topic of study. It encircles the related notions of 'energy regions' [14], 'bioenergy village' [15], and other terms referring to land affected by energy development [16]. Energy landscapes, especially those that comprise mechanical devices,

[4] Pasqualetti, M.J., Gipe, P., and Righter, R.W. (Editors). Wind power in view: energy landscapes in a crowded world. Academic press, 2002. The topic labelled "energy landscapes" is completely missing in the 19 essays included in George Thompson's 1995 book, *Landscape in America*, University of Texas Press. Nor does it make an appearance in the 16 essays found in James Corner's *Recovering Landscape*. Princeton Architectural Press. 1999. However, images of energy landscapes have been lately appearing in the work of professional photographers, such as Bernard Lang (website: http://www.bernhardlang.de/Website/AV_Coal_Mine_ALL.html, Accessed 16 September 2017), and Edward Burtynsky (website: http://www.edwardburtynsky.com/site_contents/Photographs/Oil.html, Accessed 16 September, 2017).

Fig. 4. Beyond the Wave, an example of "renewable energy can be beautiful". All the waving pink fabrics are made of pliable solar cells, thereby generating electricity as they are exposed to sunlight. A submission to LAGI 2014 Copenhagen. Jaesik Lim, Ahyoung Lee, Sunpil Choi, Dohyoung Kim, Hoeyoung Jung, Jaeyeol Kim, Hansaem Kim (Heerim Architects & Planners). Image courtesy of the Land Art Generator Initiative.

have become iconic representations of our continued interference with nature.

Because energy landscapes are still a fresh topic of academic and lay consideration, it is helpful to delineate them by providing examples. One assumes that coal strip mines, oil well fields, refineries, power plants, and wind parks could be labeled "energy landscapes" without much argument, as reflected in the emerging literature [17]. To us, it also includes landscapes recreated into functional designs for public benefit (Fig. 3), and even as works of art (Fig. 4). The latter development involves the activities of architects and other designers and, most importantly, aesthetics in the shaping of land.[5]

As landscape signatures grow in number, defining energy landscapes has become "particularly expansive" [18]. One might ask, for example: what types, forms, and landscape origins should be considered for research? How should the definition of energy landscape be delimited? Certainly, one would include a coal-burning power plant, but should we also include forests killed by acid rain resulting from operating the plant, or the factories where pollution control devices are manufactured? These considerations are yet to be sorted out, but for now we advocate excluding landscapes that originate *indirectly* from energy developments, because it quickly becomes a vexing question where to stop in considering the origins of the chain of landscape modifications.

One pragmatic approach is to develop a *de facto* definition of energy landscapes by examining published usage (Table 1). Some of the key references refer to them as being characterized by one or more elements of the energy chain (e.g. energy extraction, processing, transport, storage, transmission) [19]. The outcome can be a multi-layer energy landscape comprising combinations of technical and natural sources of energy within a landscape. In RELY, energy landscape is focused on RE and the impact on landscape quality. Both definitions refer to the purposefulness of energy development, appropriately setting energy landscapes within the literature mentioned above, while setting them apart from natural landscapes, such as the springs and geysers created by geothermal energy in the Yellowstone National Park. This leaves us with the following working definition of energy landscapes: ***Observable landscapes that originate directly from the human development of energy resources***.

4. Developing a typology of energy landscapes – a conceptual framework

Our goal in developing a typology of energy landscapes is to shed further light on the origins and the many visible expressions they assume, while at the same time recording the current stage in the development of their study for future generations. Such a conceptual framework helps ground different notions of energy landscapes as it advances the discourse about its importance to those with energy interests. Because of their specific focus on landscapes, this approach is especially applicable to those affiliated within the disciplines of Geography, Landscape Architecture and Spatial Planning. The first step in developing a typology is to set forth several conventions based on the literature we cited earlier:

- All types of energy landscapes originate from activities *directly* related to energy developments (such as well fields) and exclude those *indirectly* related to energy developments (such as factories that manufacture pumps for oil extraction).
- Energy landscapes that are constructed to access conventional energy resources tend to be extractive, whereas renewable energy landscapes tend to be supplemental (energy technology and other infrastructure).
- Renewable energy sources such as wind and solar have lower energy densities and therefore usually require more land per final unit of power provided [20].
- Public attitudes toward energy landscapes are prone to change with time. Some of the energy landscapes that faced opposition during construction are now listed as UNESCO world heritage sites [21].
- Conventional energy landscapes, especially nuclear, have greater permanence than renewable energy landscapes [22].
- Renewable energy landscapes hold greater potential for post-energy use because site contamination is generally less intense while many interventions are reversible in nature [23].

[5] The goal of the Land Art Generator Initiative (LAGI) is to accelerate the transition to post carbon economies by providing models of renewable energy infrastructure that add value to public space, inspire, and educate—while providing equitable power to thousands of homes around the world. (Website: http://landartgenerator.org/LAGI-2014/41291312/, Accessed 16 September, 2017).

Table 1
Different expressions of 'energy landscape' and associated aspects of concerns (based on Stremke, 2015).

Expression	Author(s)	Energy (general terms)	Renewable energy	Demand reduction	People	Planet	Economy
Wind-energy landscapes	Möller [24]	x	x	–	x	–	–
Landscapes of energies	Nadaï and Van Der Horst [25]	x	x	–	x	(x)	–
Landscapes of carbon neutrality	Selman [26]	x	x	x	x	–	(x)
Sustainable energy landscapes	Stremke [27]	x	x	x	x	x	(x)
Renewable energy landscapes	Van der Horst and Vermeylen [28]	x	x	–	x	–	(x)
Third generation energy landscapes	Noorman and de Roo [29]	x	x	(x)	(x)	–	(x)
Energy landscape	Blaschke et al. [30]	x	x	–	x	x	x
Alternative energy landscapes	Jørgensen [31]	x	x	(x)	–	x	–
Energy landscapes of the sustainable economy	Pasqualetti [32]	x	x	–	x	x	–
Energyscape	Howard et al. [33]	x	x	x	x	x	–

Note: Aspects that are discussed in depth by the author(s) are marked with "x". If they acknowledge an aspect it is marked "(x)" and "–" if that is not the case.

Energy landscapes may be categorized in several ways. Informing the discourse – along the challenges introduced above – we suggest starting with the following three differentiations:

1. Substantive qualification: The type of energy resource directly influences the physical appearance of energy landscapes. Energy density can help to further organize the different types of energy landscapes. It may range from relatively low (e.g. biomass) to high density (e.g. uranium mine).
2. Spatial qualification: The appearance of energy landscapes is determined by the spatial expanse and the visual dominance of energy infrastructure. In some cases, infrastructure constitutes one of many landscape components (e.g. wind turbines). In other cases, energy development is the sole land use, and the resulting energy landscape can be conceptualized as an entity (e.g. coal strip mine).
3. Temporal qualification: The degree of permanence of energy landscapes – like other landscapes – may range from relatively dynamic (due to short life cycle of technologies and reversibility of interventions) to permanent (changes manifest almost indefinitely).

These three characteristics are 'nested'. That is, the *spatial* characteristics depend on the *substantive* characteristic, while the *temporal* characteristics depend both on the *substantive* and *spatial* ones. Each of the following three sub-sections focuses on one qualification and, together, provide a framework for further elaboration (Table 2).

4.1. Substantive qualification

Some energy landscapes are commonplace while others present visible iconographic images of how we harvest energy [34]. Visibility favors the use of photographs to convey the substance of the energy landscape that each resource creates from its own inherent and identifiable characteristics. The montage in Fig. 5 illustrates different appearances of oil, coal, wind, hydro, solar, nuclear, geothermal and biomass energy developments. Elsewhere, the form of resource with its strong influence upon the physical appearance of an energy landscape has been described as 'construct' [35]. Considering advancing a systemic typology of energy landscapes, we refer to this differentiation as 'substantive qualification'.

Resources that give rise to energy landscapes vary in energy density. They range from biomass on the low end to uranium on the high end. In the case of electrical generation, energy density of the fuel influences the economically tolerable distance between the point of extraction and the power plant. For example, power plants fueled by lignite (which has a low energy density) must be sited close to mines, whereas nuclear power plants (which use a fuel with a high energy density) can receive uranium from the other side of the planet without incurring meaningful additional transportation cost. We offer a way of organizing and differentiating energy landscapes according to their substantive characteristics (Table 3).

The substantive qualification provides the visual clues to the energy resource – each one creating its own unique landscapes. For example, surface coalmines require relocation of unmistakably massive amounts of overburden. Oil fields depend on a scattered field of pumps, hydro depends on dams, wind on turbines, wood on forests, and so on. For geothermal generation, it becomes a subtler, but usually still simple, matter to identify operations by the steam/water gathering network that supplies the power plants. Likewise, nuclear generation is easily identifiable from the unique appearance of containment buildings. Beyond those examples, it can become more problematic, if not impossible, to achieve proper identification, especially when the visual clues of energy conversion are common to different types of energy source. For example, while the appearance of cooling towers does often signal 'power plant', the presence of that infrastructure does not help identify the energy source that fuels the power plant.

Table 2
Overview of substantive, spatial and temporal qualifications, with further specification and examples.

Qualification	Substantive Qualification	Spatial Qualification	Temporal Qualification
Defined according to:	Type of energy source	Degree of spatial dominance	Degree of permanence
Organized according to:	Energy density	Infrastructure/land use	Pace of change
Range:	Low to high energy density	Component to entity	Dynamic to permanent
Examples:	Low Energy Density: Biomass energy landscape with short rotation coppice	Component: Gas wells in a landscape dominated by intensive agriculture	Dynamic: Photovoltaic park that can be removed entirely at the end of the life cycle
	Intermediate energy density: Wind energy landscape with large wind turbines	Intermediate: Small-scale Photovoltaic park in agricultural landscape	Intermediate: Coal landscape with strip mines where, after closure, another landscape is created
	High energy density: Nuclear power landscape with uranium mine	Entity: Coal landscape with strip mines where energy extraction presents the sole land use function	Permanent: Peat-extraction landscape where changes are permanent and irreversible

Fig. 5. Energy landscapes illustrating the type of energy used; (a) pump jacks at Oildale, California, USA; (b) sub-bituminous surface mine near Gillette, Wyoming, USA (c) Windmill landscape North of Amsterdam, The Netherlands[5] (Source: Wikipedia); (d) wind turbines, Iowa, USA; (e) Hoover dam and Lake Mead, Arizona/Nevada, USA; (f) solar installation surrounding airport; Neuhardenberg, Germany[6]; (g) Cattenom nuclear plant, France; (h) Palo Verde nuclear generating station, Arizona, USA; (i) Hellisheidi geothermal power plant, Iceland. (j) Biomass energy landscape in Guessing, Austria.[7]

4.2. Spatial qualification

Direct relationships exist between the energy source and the spatial appearance of energy landscapes. One factor that has implications for the amount of space required for energy development – energy density – has been introduced above. Another factor is spatial dominance – the degree to which energy infrastructure is affecting the landscape and – related to this point – the compatibility of energy with other land uses. While wind turbines, for example, may require a large commitment of land, they allow concurrent use of that land with non-energy actions [36]. For this reason,

[6] Source: Archieffoto: Neuhardenberg Solarpark (Germany). http://www.airportpark-berlin-neuhardenberg.de/solarpark/. Image from Wikipedia commons.

[7] All photographs by authors except noted otherwise.

Table 3
Types of energy landscapes, distinguished by energy resource.

	Name	Explanation/Notes	Example(s)
1.	Wind energy landscape	Kinetic energy to pump water or process materials (wind mills) or to generate electricity (wind turbines)	Kinderdijk UNESCO World Heritage, NL; Altamont Pass, California, US; Flevoland, NL
2.	Biomass energy landscape and/or barren landscape (former forest)	Dedicated agroforestry/short rotation coppice/dedicated energy-crops	Western Pomerania, DE
3.	Peat energy landscape	Peat extraction for heating, cooking and electricity generation	Veenkolonien landscape, NL; Large areas in FI and Scotland
4.	Solar energy landscape	Use of solar energy for electricity generation or heat provision	Concentrated Solar Power (e.g. Solúcar PS10) in Andalucía, ES; Solar power Gila Bend, Arizona, US
5.	Geothermal energy landscape	Use of geothermal energy for heat/power generation	Larderello Tuscany, IT
6.	Coal energy landscape	Extraction of coal for electricity generation, industrial processes and heating	Mountaintop-removal in West Virginia, US; Lusatia lignite coal mines, DE
7.	Oil energy landscape	Extraction of oil for electricity, heating, and transportation	Oildale, California, US; Midlands, Texas, US
8.	Natural gas landscape	Extraction of natural gas for electricity, heating, transportation	Groningen region, NL; Bradford, Pennsylvania, US
9.	Unconventional fossil fuel landscape	Tar sands; coal-bed methane	Fort McMurray, Alberta, CA; Rifle, Colorado, US
10.	Hydropower landscape	Collection of water and utilization of potential energy to generate electricity	Hoover Dam, Arizona/Nevada, US; Three Gorges Dam, CN
11.	Nuclear energy landscape	Extraction of uranium in mines	Uranium City, Saskatchewan, CA; Kakadu National Park, NT, AUS
12.	Collated energy landscape	Use of two energy sources	Photovoltaic beneath wind turbines in Nordhausen, DE
13.	Complex energy landscape	Use of more than two technologies within a particular landscape	Samsø, DK;

Fig. 6. Example for 'component' type of energy landscape: Samsø, Denmark (Photo by S. Stremke, 2010).

Fig. 7. Example 'entity' type of energy landscape near Heuersdorf, Germany (Photo by D. Stremke, 2009).

wind energy landscapes can be conceptualized as 'component' or 'layer' type of energy landscape (Fig. 6).

Other energy landscapes, on the contrary, may represent a distinct spatial 'entity'. In coal energy landscapes, for example, energy extraction clearly presents the predominant land use (Fig. 7). Such energy landscapes are discernable spatial entities with changing (but sharp) physical boundaries at any moment in time. More often than not, energy extraction or conversion may prohibit other land uses within or near 'entity energy landscapes' (for example, little to no housing in the proximity of nuclear power plants).

Energy transport creates spatially unique energy landscapes. Transmission lines, railroads, pipelines, highways, and canals all move energy in narrow, linear pathways. Likewise, associated hazards and needed accessibility, both directly and indirectly discourage other land uses along their rights of way. This function creates sinuous but largely empty energy landscapes. In addition, such corridors often produce a dividing function between land uses on either side of their pathway, as illustrated by an expression used to describe social classes separated from one another, as in "they come from the wrong side of the tracks". In a recent publication from the Netherlands, this type of energy landscape is labeled as 'infrastructure energy landscape' and is expected to receive much more attention in the future if the trend towards an all-electric society prevails [37].

4.3. Temporal qualification

Around the world, one frequently encounters the jarring reality of quick landscape changes. This may entail landscape transformations when something like coal is removed but also include landscape changes when some form of apparatus, like wind turbines, is added. Energy development can literally produce landscape changes virtually overnight. For these reasons, time is an important element in any discussion of energy landscapes. This is what we refer to as *temporal qualification* of energy landscapes. The temporal characteristics of energy landscapes may range from relatively dynamic (for example, solar energy landscapes) to effectively permanent (for example, open-pit uranium mines).

Another concept that helps to further qualify the temporal characteristics of energy landscapes is the concept of *reversibility* – the capability to reestablish the original condition after energy development is completed. The reversibility of changes is an important parameter in the planning and design of future energy landscapes [38]. Reversibility, in effect, constitutes another continuum along which each energy landscape can be positioned. At one end of the continuum, we find energy landscapes whose changes are reversible. Wind energy landscapes fall into this category. At the other end of the continuum are those landscapes that are effectively off-limits to steady human activities. Nuclear energy landscapes fall into this category [39]. A strong correlation exists between the degree of *permanence* and degree of *reversibility*. Permanent energy landscapes are, by definition, irreversibly altered in some way. Mountaintop removal for coal extraction offers one example. Likewise, energy landscapes created by careless oil development can stymie the potential to reverse change and limit future use (Fig. 8).

As one might suspect, the life span of energy landscapes depends on the technology being considered, public opinion, environmental conditions, and many other factors. This is particularly relevant when we consider the growing practice of *recycling* energy landscapes. The common sequence for many energy landscapes in the past "use, abandon, forget" is slowly being abandoned in favor of the more sustainable notion of "use, repurpose, reuse". One example of this approach is occurring in Ukraine. In 2016, the national government announced the plan to convert the Chernobyl wasteland into a one gigawatt solar farm. Thirty-nine consortia have applied to build solar plants in the contaminated 'dead zone' adjacent to the shuttered Chernobyl nuclear power plant, now that the site has been secured by a semi-permanent dome [40].

While some energy landscapes are being *recycled*, we also witness the *upcycling of* energy landscapes. In these cases, the environmental integrity and performance of the present stage exceed those of the previous stage. One country where this is occurring is Germany, where a substantial national program recycles lignite mines for recreational and leisure purposes. One example of upcycling includes the so-called Metabolon, a former waste hill in Dusseldorf/Germany (Fig. 9).

Finally, energy landscapes exist over a wide temporal range in various *forms*. There are those that existed in the past but have disappeared due to reclamation or natural succession. There are those that exist at present and have an uncertain life expectancy. In addition, there are those that will exist in the future, either created afresh or recycled from pre-existing energy landscapes. In some places, one can find traces of past energy landscapes which help to understand the *sequence* of energy landscapes that evolved over time. The historical development of energy in a landscape, like other land uses, is an expression of

Fig. 8. Chaotic oil field development creates a jumbled landscape at Oildale, California, USA. (Photo by M. Pasqualetti).

Fig. 9. Tiger & Turtle Magic Mountain, is an example of upcycling. It rests atop waste heaps from decades of nearby coal mining in Duisburg, Germany [41].

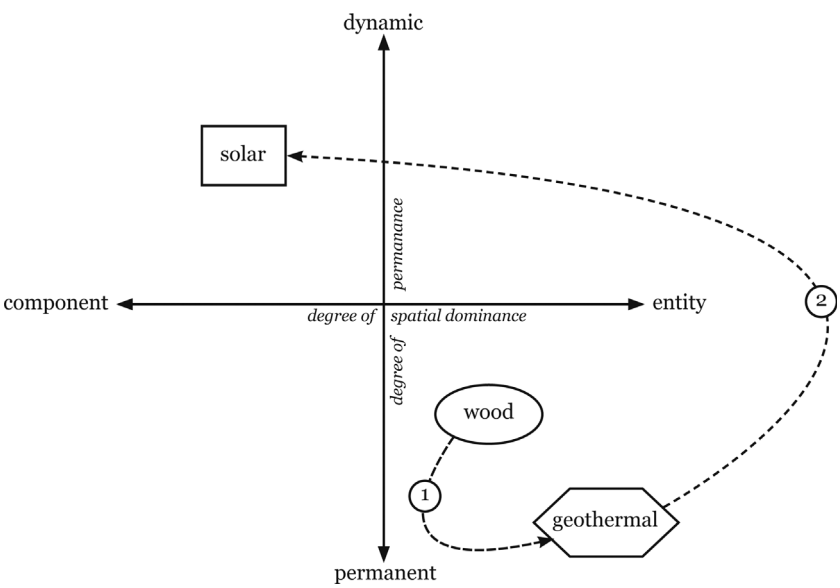

Fig. 10. Exemplary visual representation of the different types of energy landscapes that have evolved in Viterbo/Italy: From wood to geothermal (first transformation) and later to solar energy (second transformation).

changing relations between people and their living environment. In Viterbo/Italy, for example, a geothermal energy landscape has replaced the historical wood landscape that provided biomass. More recently, this site has been turned into a collated energy landscape that is hosting both geothermal and solar energy technologies.

The three main qualifications put forward in this paper can be illustrated in diagrammatic form (Fig. 10): Symbols refer to the *substantive characteristics* (energy sources), *spatial characteristics* are expressed along the horizontal axis (from component to entity), and *temporal* characteristics expressed along the vertical axis (from dynamic to permanent). Viterbo serves as a mere example of how to represent the evolution of energy landscapes on a particular site.

5. Discussion and conclusions

Energy landscapes can be found in many places, varieties, and origins and, for many reasons, they are proliferating in size and numbers. They can be confronting, challenging the willingness to accept change and responsibility, morphing from one use to another, and affecting the promulgation of legislation and policy in a world of growing population pressure and limited natural resources. The goal of this paper has been to shed light on the topic of energy landscapes, exposing them to deeper examination with the help of photographs, and eliciting continued thought about how to develop a typology that does justice to the great diversity of energy landscapes – landscapes that used to be, that exist, and that ought to be developed. It remains noteworthy that, to our knowledge, no systematic typology of energy landscapes has been published before, other than the substantive characteristics that we discussed as first qualification in this paper.

We distinguish three main characteristics of energy landscapes: (1) *Substantive qualification*, because the appearance of energy landscapes result from dominating energy sources; (2) *Spatial qualification*, because energy landscapes may range from hardly recognizable components of the larger environment to distinct spatial entities; and (3) *Temporal qualification*, because landscape permanence varies significantly from highly dynamic to virtually permanent. One can place all observable energy landscapes that originate from the human development of energy resources within this three-tier conceptual framework.

We wish to be clear that the definitions and qualifications we offer are not sacrosanct. Indeed, our intent has been to initiate a more informed discussion, while encouraging the drafting of a conceptual framework that considers many energy landscape characteristics. We found a limitation of generic types of energy landscapes. That is, many variations

may exist in different places around the world, and the list of energy landscapes is flexible in its detail. For this reason, the list of energy landscape can be expanded, following further consideration and evaluation within the realms of public policy and academic discourse. We invite additional discussion, refinement of characteristics, and possible additional qualifications, such as *prevailing agency* in development of energy landscapes (for example, local inhabitants, commercial enterprises or governmental bodies) and *degree of energy independency* (for example, relying on import of resources, self-sufficient or energy exporting).

Another additional way to qualify energy landscapes is by function; that is, energy landscapes vary according to their stage on the energy chain. Such stages for conventional energy resources include extraction, processing, transportation, conversion to electricity, transmission and waste disposal. Each stage holds particular spatial characteristics that influence their landscape signature. For example, extraction is often vertical, such as excavating an underground shaft. Transportation is linear, mobile, and (often) dividing. Power plants are stationary 'hubs'; transmission corridors are linear and immobile; waste disposal landscapes are essentially permanent.

Another aspect that deserves careful consideration when applying the framework proposed here is where to 'place' an energy landscape under consideration along the dimensions (see for example Fig. 10). An energy landscape that is considered flexible in one place may be considered permanent in another place. In short, the nature of any energy landscape is relative and any discussion in generic terms is limited. This does not prevent advancing the larger conversation on energy landscapes, their epistemology as well as their phenomenology. One of the strengths of the proposed framework lies in the illustrative power of diagrams that describe how a landscape has evolved through time and that can clarify the differences between energy landscapes in one location or elsewhere.

One of the general insinuations of this paper is pedagogical. That is, how can the proposed framework incite further research, teaching, landscape planning and design practice, policy design and governance? The substantive qualification proposed here coincides with a common practice of naming energy landscapes according to the prevailing energy source [42]. Lower density of renewable energy sources will result in increased land use for energy provision, compared with conventional energy sources, which in turn implies further research into multifunctional land use and the coupling of energy development with other challenges such as urbanization and water storage.

The spatial qualification, too, suggests both research and practice. 'Entity' energy landscapes require substantially different decision-making processes compared with 'component' energy landscapes. Whereas the former may be indifferent from large-scale transport infrastructure projects which are developed by higher governments through robust legal frameworks and (what we now may call) conventional planning procedures, the latter type of energy landscapes seems to 'flourish' through more participative planning and design processes, at least for a selection of renewable energy sources [43].

The temporal qualification also has implications: Wind turbines and large-scale solar energy installations, for example, can be used to temporarily discourage other developments. If placed strategically, they prohibit the encroachment of peri-urban landscapes by new suburbs. More importantly, the third qualification serves as a reminder that many of the renewable energy landscapes are reversible in nature and that the interventions, if done well, are of temporary nature. Either way, planners and designers need to embrace the concept of life cycle and apply strategic thinking when dealing with energy landscapes.

We encourage continued testing and consideration of the proposed framework through research, planning and design practice as well as teaching. One of the immediate needs is the development of a catalog of energy landscapes in different nation-states and internationally.[8] A typology of energy landscapes helps in many ways, such as framing discussions on low-carbon energy futures (e.g. National Perspective on Energy and Space in the Netherlands) [44], facilitating studies of historical energy landscapes (e.g. Dutch historical energy landscape research project) [45], and articulating qualitative criteria for future energy landscapes (e.g. Parkstad Limburg Energy Transition project) [46]. Addressing these and a growing number of associated questions will promote more thoughtful protection of the landscapes we inherit while paying closer attention to the relationships between ourselves and the landscapes that surround us..

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