Energy-space concept for the transition to a low-carbon energy society

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Abstract
Urban and regional development is indispensable from energy systems that function in a sustainable and resilient manner. The generation of renewable energy has seen significant upturn in the last decade. Renewables can be exploited to meet the global energy needs and climate change mitigation goals. Therefore, development of urban and regional energy systems must take into account the possibilities and challenges posed by the increasing penetration of the renewable. The achievement of goals of the energy system in the context of transition to low-carbon energy society rises numerous complex decisions over development of infrastructure and technologies. Although renewable energy devices generate clean energy, they also change landscape. The term of energy-scape encourages discussion about interactions between the energy system and the environment, and other ecosystem services at local level. The paper reviews previous studies analysing energy-scape elements and provides the insights towards the transition to low-carbon energy and low-carbon society in general. The systematic literature review allows clearly outlining the problem and gives reliable background for further studies. The main contribution of the article to the existing literature is the creation of framework for the analysis and assessment of new renewable energy technologies installation and infrastructure. The presented framework can be applied for all renewable energy technologies and infrastructure in both urban and rural areas and allows to attain a decision acceptable to the local community.

Keywords Energy-scape · Low-carbon energy · Energy transition · Renewable energy · Energy infrastructure · Landscape

1 Introduction
The transition to low-carbon energy is a major goal for many governments across the world (Rus et al., 2020). Even though the world has become more globalized in recent decades, certain warnings have emerged that call for further attention to energy security and resilience amid the sustainability objectives. The urban systems are particularly dependent on
the energy supply. In the case of Europe, Russia’s invasion in Ukraine and its repercussions in the energy markets have all reaffirmed that the dependence on imported energy resources may have negative consequences for the country’s economy, social stability and energy security (European Commission, 2022). At the same time, increasing volatility in the energy markets exerts multiple negative consequences for individual energy consumers, such as rising energy poverty among households, the decrease in quality of life, rising prices for final products and services. Therefore, the upgrading of renewable energy infrastructure constitutes the main measure to ensure energy security and energy independence at country and individual level.

1.1 Economic growth and impact on the environment

Energy generation and consumption have very strong links to the economic welfare and impact on the environment. The empirical results showed that growth of the economy (Adedoyin et al., 2021) and agricultural land expansion stimulate the environmental degradation, while the increase in the usage of renewable energy improves the quality of the environment (Raihan & Tuspekova, 2022). The achievement of current goals of energy system in the context of transition to low-carbon energy society rises numerous complex decisions over development of infrastructure and technologies. These questions are actively addressed in the political documents and scientific literature, especially in the last decade. The scientists argue that the generation of electricity in sustainable way is the main core in reducing greenhouse gas (GHG) emissions. Renewable energy technologies for electricity generation such as solar, wind or hydro allow substitution of fossil fuels and can be used to meet energy needs in households, industrial, commercial and transport sectors. The concern on the environment, climate change and energy deprivation rose the political interest in low-carbon cities development in recent years (Griffiths & Sovacool, 2020; Hadfield & Cook, 2019; Lv et al., 2022). The development of low-carbon cities and the performance depend on how new innovative technologies and policy measures are applied and how successful acceptable they will be in the community (Geels et al., 2018). The analysis of the impacts of institutional quality and renewables on the quality of the environment in Emerging 7 economies showed that weak institutions dampen the environmental quality (Bekun et al., 2021). Also, there are the positive links between public and private partnerships investment in renewable energy and CO2 emissions reduction (Caglar et al., 2022). As highlighted Drozdz et al. (2021), it is very important to involve local communities in the decision-making and boost the degree of social acceptance of new technologies. The reshape of energy system can be achieved by the development of large-scale renewable energy generation infrastructure or by development of small-scale renewable technologies and community ownership models. This caused a lot of challenges for policy-makers. Public opinion and acceptance of large-scale infrastructure projects and (particular) renewable energy technologies are very important issues for technology development (Boudet, 2019; Walker et al., 2018; Wolsink, 2018).

1.2 Public acceptance of new renewable infrastructure

Numerous scientific studies were performed to explore community preferences and acceptability of large-scale renewable energy projects. One of the first studies introduced the importance of local community engagement and public acceptance for renewable energy projects was by Wolsink (1987). It was determined that socio-economic
factors as age, gender, education, disposable income and socio-psychological factors such as information and experience regarding particular renewables, political affiliation and environmental and climate concern (Büscher and Sumpf, 2015; Koirala et al., 2018; Donald et al., 2021) have impact on people’s perception and the social acceptance of different technologies (Cousse, 2021). The public acceptance and expectations among different renewable energy technologies vary across countries (Segreto et al., 2020), but it should be noted that this question is still a problem in many of them (Bout et al., 2021; Haque et al., 2021; Kost et al., 2021). Among the key points to be considered as those influencing the acceptability of renewable energy projects, emerges the impact of renewable energy infrastructure to the landscape (Cohen et al., 2014; Lennon & Scott, 2017; Manyoky et al., 2016; Spiess et al., 2015; Vuichard et al., 2021). Indeed, there have been multiple effects on the landscapes due to implementation of renewable energy projects and further adjustments are imminent.

1.3 Low-carbon energy development and landscape

The issues of public acceptance of renewable energy projects and interrelations with the landscape issues have been analysed in the scientific literature for more than thirty years. For example, Pasqualetti and Butler (1987) examined public response to implementation of wind power projects in California. Thayer and Freeman (1987) looked into the social acceptability of wind power projects from the viewpoint of landscape management. Wolsink (1988) measured public perception of wind-generated electricity in the Netherlands. The public acceptance of adjustments in surroundings due to the new renewable energy projects is influenced by many aspects. These aspects can be grouped into three main categories such as: landscape and environment, renewable energy infrastructure and public response category. Environmental concern and values (De Salvo et al., 2021), knowledge about the landscape, landscape aesthetics and heritage (Oudes & Stremke, 2021), and landscape services (e.g. the provision of habitats) have significant influence for public acceptance (Hastik et al., 2015; Ioannidis & Koutsoyiannis, 2020; Kienast et al., 2017). Also, non-landscape elements play an important part for public acceptance. The perception and opinion about renewable energy (Saeporsdottir & Olafsdottir, 2020), political affiliation (Lintz & Leibenath, 2020), assessment of personal or societal costs due to new infrastructure and also psychological response to the landscape view (Spielhofer et al., 2021a), and demographical characteristics of people (Westerlund, 2020) can have impact on the public acceptance for the development of new renewable infrastructure (Cohen et al., 2014; van der Horst, 2007).

The generation of renewable energy has seen an upturn trend in the last decade. It is known that renewable energy exerts profound possibilities to meet the global energy needs and to meet climate goals. Renewable energy technologies reshape landscape elements, but generate clean energy. The quantitative decision support tools have been developed to improve the landscape management associated with the installations of the renewable energy generation (Eichhorn et al., 2017; Soha et al., 2017). Also, recent studies assessed the acceptability of the renewable energy systems from different perspectives (McKenna et al., 2022; Wang et al., 2021). Still, the overarching conceptual framework has not been explicitly addressed in the literature. The term of energy-scape encourages discussion about interactions between the energy system and the environment, and other ecosystem services at local level.
1.4 Aim of the study and contribution to the field

This paper seeks to review previous studies analysing energy-scape concept and present a framework for the analysis and assessment of new renewable energy technologies installation and infrastructure. To the best of our knowledge, there have been no systematic literature reviews on the implementation of the energy-scape approach. The systematic literature review allows a clearly outline of the problem and provides a reliable basis for subsequent studies. The main contribution of the paper to the existing literature is the creation of framework for the analysis and assessment of new renewable energy technologies installation and infrastructure. The presented framework can be applied for all technologies and allows to achieve a decision acceptable to the local community. The current review is based on the guidelines of the Protocol, Search, Appraisal, Synthesis, Analysis and Report framework (PSALSAR) (Mengist et al., 2020a, 2020b), which includes both the framework of Search, Appraisal, Synthesis and Analysis (SALSA) (Amo et al., 2018) and the methodology of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2010). The literature search was carried out in the Web of Science Core Collection database.

The second section of the article deals with the methodology that was followed for the systematic literature review. The concept of energy-scape and the relationship with landscape elements, the connection with ecosystem services and literature review of existing studies are presented in the third section. The fourth section is dedicated to the creation and presentation of framework for the analysis and assessment of new renewable energy technologies installation and infrastructure. Conclusions and future research directions are presented in the end of the article.

2 Methodology

The systematic literature review follows the PSALSAR framework, which was introduced by Mengist et al. (2020a). The framework is constructed from six steps by integrating SALSA and PRISMA methodologies. Also, the snowballing technique was applied in order to expand the literature search and include all relevant studies regarding the topic as possible. It allows a performance of in-depth analysis of the academic studies, to minimize the possible subjectivity and to guarantee methodological precision of the research (Grant & Booth, 2009). The outline of the research procedure is presented in Fig. 1.

The first step of the research procedure seeks to clearly confine the research by explicitly defining its scope. The research protocol allows to ensure repeatability and transparency of the research. Scientific articles dealing with energy-scape elements and renewable energy, sustainable energy development, and transition to low-carbon energy society are target sources. Achievements, trends, gaps, challenges in the field, and approaches used are the main questions for content analysis.

The literature search was performed in the Web of Science Core Collection database on such topics as “energy-scape”, “energyscape” and “energy scape”, as there is no uniform spelling in the literature. Also, the inclusion and exclusion criteria were determined. One inclusion criterion was selected: a relevant keyword should appear in the title, abstract, or keywords section. The following exclusion criteria were maintained: conference proceedings, review papers, editorial letters, non-English studies, duplicate search results are not to be maintained.
for further analysis. Finally, 121 articles were included in content analysis. Also, the snowballing was used in order to expand the search.

The inclusion and exclusion criteria were exploited in the appraisal step. The results of the search step were then filtered out by means of the inclusion or exclusion rules, i.e. only papers that meet at least one admissibility rule and do not meet any rejection rules were retained for further processing. Articles that do not correspond to the problem under the analysis were also eliminated in this step. Also, the quality criterion was followed: further analysis was based on selected articles that did not rise doubts about the methodology of the study.

The relevant data were extracted and summarized into categories in the synthesis step. Such data as the year of publication, outlet, country of the case study, scale of the assessment, analysed renewable energy technologies can be considered as general variables. Other data that relate to particular questions pertinent to the research topic can be considered as specific variables. The latter variables may include such information as strategy of the research, applied approach, the methods applied, spectrum of analysed ecosystem services, aim and main findings of the study.

The classified data were analysed, the results were compared, trends and gaps were identified, and results of the analysis were discussed in the analysis step. Finally, the summarization of the research results, presentation of conclusions and recommendations, and identification of future research directions were performed in the report stage.
3 The application of energy-scape concept: literature review

Energy-scape concept is quite new, and it is only just beginning to be used more actively in the scientific literature. This section reviews the term energy-scape, reveals linkages with landscape elements, defines the relationship with ecosystem services and embarks on an in-depth discussion on studies using the notion of energy-scape.

3.1 The definition of term

The term energy-scape was introduced in 2007 to develop a long-term energy plan for New Zealand (de Vos & NIWA, 2009). Since then, the term has started to be used in the scientific literature. The term of energy-scape encourages the discussion and analysis about the energy system elements and their relationship with the environment, and other ecosystem services at local level. A broad analysis of understanding of the term was performed by Howard et al. (2013). Relying on the energy-scape approach allows to embed particular elements of the energy infrastructure (development) in response to the local demand for energy resources and encourage the local communities to adopt reasonable and transparent decisions in regard to the renewable energy development. The definition and concept of the energy-scape term in various scientific sources are given in Table 1.

In summary, energy-scape elements are renewable energy installations and all the necessary infrastructure to supply the energy generated. Undoubtedly, new infrastructure and technologies have a directly visible and invisible impact on the nature- and human environment. New renewable energy projects change landscape elements and have a direct impact on various ecosystem services.

3.2 The relationship with landscape

Energy-scape is integrated in the landscape and its elements with focus on renewable energy technologies and infrastructure to transmit the generated energy. Different

| Reference | Definition |
|-----------|------------|
| Saelens et al. (2006) | Energy-scape elements integrate landscape elements with devices of renewable energy |
| Howard et al. (2013) | Energy-scape—the compound spatial and temporal combination of the energy supply, demand and required infrastructure within a landscape |
| Moussa and Mahmoud (2017); Moussa et al. (2020) | Energy-scape elements are sustainable landscape elements that share its properties while generating clean energy with integrating renewable energy technologies with these elements |
| Moussa (2018) | Energy-scape is a sustainable element that can change landscape elements and generate clean energy |
| Statuto et al. (2019) | Energy-scape—the effect derived from the role played by energy sources as a force in shaping the visible features of the Earths surface in delimited areas |
| Delina (2020) | Energy-scape includes the energy technologies, required infrastructure and systems and also the structural arrangements and institutions that make up an entire ecology of what can be called an energy sociotechnical system |
categorization of landscape elements is provided in the literature (Valles-Planells et al.,
2014; Atik et al., 2015; Drive, 2015; Massimo et al., 2019). Elements of the landscape
reveal the connections between the landscape and human activity. For example, Huang and
Sherk (2014) categorized residential landscape elements into the four categories: water,
planting, gathering, and circulation area; Kim et al. (2021) analysed pedestrian space ele-
ments and preferences of pedestrians’, where twenty-seven landscape elements only in
urban area were singled out; in the study by Fang et al. (2021), landscape elements were
grouped into the greenness, blue spaces, public squares, garden architecture and sport
spaces, walking trail systems, etc.

However, most studies applying the energy-scape concept follow the categorization of
landscape elements presented by Saelens et al. (2006). The latter study created an instru-
ment for the environmental assessment of public recreation areas and identified five cat-
egories of the landscape components: 1. trail/path; 2. designated and specific use areas; 3.
water areas; 4. other amenities and facilities; and 5. playground equipment and fields and
courts.

The presented categorization is quite universal and is easily applicable not only to the
analysis of parks and recreation areas, but also to the landscape in general. For example,
category “Designated and specific use areas” includes not only elements for recreation as
picnic area, camping site, shelter, entertainment venue or parking lot, but also such ele-
ments as open space, meadow, wooded area, wildlife area. Therefore, this categorization of
landscape elements has been applied in most of the surveyed studies dealing with energy-
scape components (Moussa and Mahmoud, 2017; Moussa et al., 2020; Moussa, 2018;
Moussa & Dewidar, 2020). Most of the landscapes are related to a number of different
functions relevant for the population. Therefore, many aspects need to be discussed and
considered in order to analyse different planning alternatives.

### 3.3 The connection with ecosystem services

Clean energy can be generated by employing renewable energy installations. Still, the
majority of renewable energy technologies make significant changes in the landscape.
These technologies require large areas for the installations themselves and power networks.
All of these impact the landscape elements (Pang et al., 2014) and, as a consequence, eco-
system services. For example, a wind farm changes view, a hydro-power installation can
change landscape physical structure (river course, fauna and flora, ecological integrity and
various ecosystem services). Communities often object to establish new infrastructure
of large-scale renewables because of the possible landscape transformation and changes
of ecosystem services. One can note that certain alterations in the surroundings are also
caused by the exploitation of the fossil fuels. Yet, the spatial footprint of the renewables is
more vast in comparison with the fossil energy (Pasqualetti & Stremke, 2018).

Ecosystems are the sources of certain benefits (whether products pr services) that are
enjoyed by the human population. These services are termed ecosystem services. The lit-
erature defines multiple types of the ecosystem services (Boyd & Banzhaf, 2007; Howard
et al., 2013). However, it was the Report of the Millennium Ecosystem Assessment that
clearly formulated the underlying linkages between human well-being and ecosystem ser-
vices. In the report, the four types of the environmental services were outlined (Reid et al.,
2005):

- **supporting services** (soil formation, primary production);
• **provisioning services** (water, food, fuel);
• **regulating services** (air and water quality, climate, diseases);
• **cultural services** (aesthetic, recreation, scientific, heritage).

The categorization allows a clear view of the value of ecosystem to human society and provides a framework to analyse and assess different services of nature through the goods and services provided. Other good example of the relationship between human and natural environment was provided by Groot (2006) who grouped ecosystem functions in the following manner: *regulation, habitat, production, information, and carrier functions*. Also, an overview of the ecosystem services in natural and cultivated landscapes was provided in the latter study. According to Groot (2006), the value of ecosystems comprises the three dimensions of sustainability, viz. economy, environment, and society. The ecosystem potential to maintain the provision of services and goods relies on the nature of the ecosystem and the sustainable exploitation thereof. The socio-cultural value of ecosystem is related to the information functions. The economic value of goods and services resulting from the exploitation of the ecosystems may be expressed in monetary sense.

However, despite the importance of ecosystem services, they do not receive the attention they deserve by developing new renewable infrastructure. Figure 2 provides the popularity to consider ecosystem services in different literature sources under analysis:

Consideration of ecosystem services in different scientific studies is presented in Table 2:

The visual aspect of new renewable energy technology and its infrastructure is the main factor for planning the integration of energy-scape elements into landscape elements, especially in urban areas. Many scientific studies analysed how public evaluate different renewable technologies focuses on aesthetics (Cohen et al., 2014; Devine-Wright & Batel, 2013; Salak et al., 2021; Valtchanov & Ellard, 2015). The aesthetic factor is most likely noticeable and it is expressed first, e.g. Betakova et al. (2015) found that high-devices occupied landscapes are considered as lower-quality compared with low-occupied landscapes. Spielhofer et al. (2021a) confirmed that people are more physiologically aroused while noticing energy devices occupying landscapes compared to low-occupied landscapes where renewable energy installations are less obvious. Also, it was determined (Spielhofer et al., 2021b) that the aesthetic background and aesthetic matching between energy devices and landscape represent the essential factors of human aesthetic tastes (and acceptance) for...
energy-scape elements. However, more attention should be paid also to other ecosystem services when planning new projects.

Hastik et al. (2015) analysed the links between development of different renewable energy sources and their relationship with the provision of the ecosystem services. The latter study discussed the impact of biomass, hydropower, wind power, photovoltaic energy, and geothermal energy on multiple economic, social, and environmental effects stemming from the ecosystem functioning. They also highlighted the necessity for interdisciplinary research on renewables and conflicts related to the environment. Also, the analysis on the interactions between renewable energy development and ecosystems (including landscape) was presented by Picch et al. (2019) who argued that much more attention is needed for this relationship in empirical applications.

### 3.4 The application of energy-scape concept

The application of energy-scape concept is divided into three main categories according to the approach applied. These categories are: community attitude approach, measurement and analysis approach, and planning approach. The studies assigned to the community attitude approach focus on meeting needs of local people. The studies assigned to the measurement and analysis approach analyse the impact of energy-scape elements to the natural and human environment. The studies assigned to the planning approach focus on integration of renewable energy technologies with landscape elements by proposing new tools and frameworks for architects, designers and decision-makers. The summary of studies by applied approach is presented in Table 3.

Different perspectives of local people were analysed in several studies. Studies on this approach are characterized by the involvement of stakeholders. Delina (2020) analysed disagreements of local environmental defenders and community against large-scale hydro energy projects in region of Philippines. The context analysis and interviews were carried out for the explanation of narratives in the region of Cordillera, where large-scale hydro energy projects were proposed. Cronin et al. (2021) analysed the public perception of wind energy in Ireland. The results of the study showed that the public is positive about the development of wind energy. It was confirmed that potential reduction in the GHG emission positively affects adoption of wind farms. According to the respondents, the impact of wind energy technologies and infrastructure on wildlife, aesthetics, and tourism is not highly noticeable and positively supplements the sea scape. Howard et al. (2013) analysed interactions of the energy

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**Table 2** Consideration of ecosystem services by sources

| Services      | References                                                                 |
|---------------|-----------------------------------------------------------------------------|
| Supporting    | Howard et al. (2013), Baka and Bailis (2014), Statuto et al. (2019), de Jong and Stremke (2020) |
| Provisioning  | Howard et al. (2013), Baka and Bailis (2014), Statuto et al. (2019), de Jong and Stremke (2020) |
| Regulating    | Howard et al. (2013), Cronin et al. (2021)                                  |
| Cultural      | Howard et al. (2013), Moussa and Mahmoud (2017); Moussa (2018), Delina (2020), de Jong and Stremke (2020), Moussa et al. (2020), Moussa and Dewidar (2020), Cronin et al. (2021), Norouzi et al. (2021) |
### Table 3  The summary of studies by applied approach

| Approach | Source | Aim of the study | Ecosystem services | Technologies | Scale | Case study, location | Research strategy | The methods applied | Stakeholders participation | Main findings of the study |
|----------|--------|------------------|--------------------|--------------|-------|----------------------|------------------|----------------------|----------------------------|-----------------------------|
| Community attitude | Howard et al. (2013) | The analysis of interactions of the energy system with ecosystem services | x   | x   | x   | x   | Biomass | Local | Bedfordshire (England) | Stakeholder interviews | Yes | The interactions between ecosystem services and energy system were analysed; the innovative approach was presented; the importance to examine the linkages between new renewable infrastructure and landscape elements and ecosystem services was stressed |
| | Delina (2020) | The analysis of disagreements against large-scale hydro energy projects in Philippines | x   |   | x   |   | Large-hydro energy projects | Regional | Philippine Cordilleras | Qualitative Context analysis, interview | Yes | The importance of interests of indigenous peoples was stressed; narrative analysis of Cordillera region in Philippines was performed |
| | Cronin et al. (2021) | The analysis of public perception of wind energy in Ireland | x   | x   |   |   | Wind | National | Ireland | Quantitative Survey | Yes | The public perception of wind energy in Ireland was determined |
| Approach | Source | Aim of the study | Ecosystem services | Technologies | Scale | Case study, location | Research strategy | The methods applied | Stakeholders participation | Main findings of the study |
|----------|--------|------------------|--------------------|--------------|-------|---------------------|------------------|---------------------|-------------------------|----------------------------|
| Measurement and analysis | Baka and Bailis (2014) | The comparative energy capacity analysis for the development of different biomass energy sources | x x | Biomass | Local | Tamil Nadu, South India | Quantitative | Comparative energy flow analysis | No | The comparative energy flow analysis was performed; the importance to analyze natural and human environment at local level is highlighted; the recommendations for the development of sources were presented |
| | de Jong and Stremke (2020) | The analysis and evolution of Western Netherlands energy-scape | x x x | Several renewable and fossil fuel technologies | Regional | Western Netherlands | Quantitative; qualitative | Expert interviews, literature review, and map analysis | – | The approach for the analysis of energy-scape based on spatial, substantive, and temporal provision was proposed; the evolution of Western Netherlands landscape by the development of various energy sources was presented |
| Planning | Moussa and Mahmoud (2017) | The presentation of new approach for the integration of renewable energy technologies with landscape elements | x | Solar, biomass, piezoelectric cells (pavement and roads), hydro-power, wind | Local | Al-Azhar Park, Cairo (Egypt) | Quantitative; qualitative | Surveys, statistical analysis | No | The new approach for the integration of renewable energy technologies with landscape elements was introduced and justified |
| Source               | Approach                                                                 | Aim of the study                                                                 | Ecosystem services | Technologies                           | Scale       | Case study, location     | Research strategy | The methods applied                  | Stakeholders participation | Main findings of the study                                                                 |
|---------------------|--------------------------------------------------------------------------|----------------------------------------------------------------------------------|-------------------|----------------------------------------|-------------|--------------------------|------------------|--------------------------------------|---------------------------|-------------------------------------------------------------------------------------------|
| Moussa (2018)       | The replace of landscape elements with elements of energy-scape in order to create more sustainable urban area | x                                                                                | Supporting        | Solar, biomass, piezoelectric cells (pavement and roads) | Local       | Family Par, Cairo (Egypt) | Qualitative       | Expert interviews, literature review, and map analysis | No                        | The framework for the analysis was presented; the replace of landscape elements with elements of energy-scape was justified and acknowledged as efficient and useful |
| Statuto et al. (2019)| The measurement of supply and potential of bioenergy                      | x                                                                                | x                 | Biomass                                | Regional    | Basilicata Region (Italy) | Quantitative      | Geographic Information System          | No                        | The framework for distribution of renewable energy sources in the spatio-temporal context was proposed; the necessity to shape energy system in common with landscape planning was stressed; the supply and potential of bioenergy in the Basilicata Region were measured |
| Moussa et al. (2020) | The presentation of an online tool, which integrates renewable energy technologies within landscape elements in urban environment | x                                                                                | Supporting        | Solar, biomass, piezoelectric cells (pavement and roads) | Local       | Al-Azhar Park, Cairo (Egypt) | Quantitative      | Software                             | No                        | The new tool to design energy-scape elements was proposed; the validation of the tool was performed |
| Source | Aim of the study | Ecosystem services | Technologies | Scale | Case study, location | Research strategy | The methods applied | Stakeholders participation | Main findings of the study |
|--------|-----------------|--------------------|--------------|-------|----------------------|------------------|---------------------|---------------------------|---------------------------|
| Moussa and Dewidar (2020) | The validation of energy-scape software | Supporting, Provisioning, Regulating, Cultural | x | No specific technologies | National | Egypt | Qualitative | Survey | The validation of the proposed software was performed |
| Norouzi et al. (2021) | The presentation of Iran’s renewable energy possibilities by analysis of country landscape | Supporting, Provisioning, Regulating, Cultural | x | Several technologies (wind, biomass, solar, geothermal, wave and tidal energy) | National | Iran | Quantitative | Descriptive and inferential statistics, MATLAB software | No | Potential energy production from various renewable energy sources was estimated; capacities and potential to export renewable energy to neighbouring countries were identified; insights for new renewable infrastructure in the context of landscape design and aesthetic were provided |
A system with ecosystem services. The authors proposed an innovative approach, which taking into account all landscape elements and related ecosystem services. The proposed approach is useful for decision-makers and planners and allows to plan future energy system in a sustainable way. The approach takes into account different perspectives of local people, that allows to met their needs by planning new renewable energy infrastructure.

The objectives of the low-carbon society and the associated energy projects have appeared as the major stimuli for adjustments in the existing landscapes. There have been studies that evaluated the impact of energy-scape elements to the natural and human-made environment. De Jong and Stremke (2020) discussed the historical transformation of Western Netherlands landscape amid the installation of energy generation facilities of different types. In the latter study, five periods based on various energy sources have been identified: wood, peat, wind energy, fossil fuels, and recent modern renewable energy sources. The study proved that the landscape is evolving and changing with the new sources of energy and its infrastructure. The proposed approach for the analysis of energy-scape is based on spatial, substantive, and temporal provision and allows to provide an analysis of landscape changes at the regional scale. Baka and Bailis (2014) discussed the prospective development paths for India’s biomass sector and argued that attention to the local level context and linkages of new technologies with the natural and human-made environment is crucial.

Also, several studies were designed to plan the energy capacity of a country or region. Statuto et al. (2019) developed an approach to monitor the scattering of the renewable energy installations across time and space. (The case of Italy was addressed.) Norouzi et al. (2021) analysed possibilities to exploit Iran’s renewable energy resources in the context of landscape design.

Moussa and co-authors offered an array of studies on the development of the energy-scape concept in the planning of the landscape in urban environment and energy system. Moussa and Mahmoud (2017) presented an approach, which integrates renewable energy technologies with landscape elements. The authors applied the presented approach for a case study in Cairo (Egypt) urban environment. The study showed a clear example how combination of renewable energy installations with landscape components may render a more sustainable urban environment and reduce GHG emissions. Moussa (2018) evaluated the possibility to create more sustainable urban area by changing some landscape elements with energy-scape elements, i.e. renewable energy installations. Such alternatives lead to a decline in the demand for fossil fuels. The proposed framework was employed to consider the instance of applied for the case study in a park of Cairo (Egypt). The results confirmed the need for considering the energy-scape traits throughout the decision-making process. Moussa et al. (2020) proposed an online application that integrates renewable energy technologies within landscape elements in urban environment. The tool was created for architects, designers, and policy-makers to stimulate the development of infrastructure for renewable energy. The proposed tool allowed to modify location in accordance with the needs of a particular installation and resource constraints. The usefulness of proposed software was also validated by Moussa and Dewidar (2020) who argued that the interactive tools may improve the abilities of the architects (dealing with buildings and parks) in regard to the renewables. The appropriate software dedicated to energy-scape management may contribute to the cleaner energy production by allowing architects and landscape designers to seamlessly implement renewable energy technologies in outdoor spaces.
The promotion and penetration of sustainable energy represent a central element of climate and energy policy in many developed countries. The importance of energy transformation is well-known for policy-makers and much of the society. Anyway, finding socially acceptable loci for new energy infrastructure poses a cumbersome task. The lack of knowledge and social acceptance often renders an opposition of the local communities against the potential; renewable energy installations (Kienast et al., 2017; Sutterlin & Siegrist, 2017).

Different studies showed that despite the positive community perception regarding renewable energy and its impact to climate change, the possibility to face undesirable external outcomes and alterations in the landscape causes a resistance (Dugstad et al., 2020; Oehlmann et al., 2021). The inclusion of energy-scape elements into the landscape change ecosystem services that are related to human health, food, recreation and other basic needs. And conversely, the farther people live from new technologies and infrastructure planned, the more they accept new renewable energy projects (Meyerhoff et al., 2010). Therefore, it is very important to consider preferences of the local communities and social costs they face to ensure a transition to low-carbon energy society. Based on the scientific literature analysis and the identified links between energy-scape elements and landscape elements and ecosystem services, the framework for the analysis and assessment of new renewable energy projects is prepared and presented in Fig. 3. The proposed framework is suitable for both urban and rural areas renewable energy infrastructure development.

The replacement of fossil fuels with renewable energy, energy conservation, and energy efficiency gains is the key elements that may secure implementation of the goals related to
the creation of the low-carbon cities and society. The aforementioned objectives imply that new energy projects should be enacted in a sustainable way ensuring balance among multiple stakeholders. The perspectives and values of stakeholders are one of the most important components in sustainability assessment of energy system (Cebrian-Piqueras et al., 2017; Dale et al., 2018). The understanding and integration of multiple conflicting viewpoints in decision-making allow to attain public acceptability and higher level of perception of clean technologies. In order to ensure the social acceptance for new renewable energy projects, different groups of stakeholders should be engaged in planning and assessment stage of new projects. Mainly landscape issues receive the most opposition (Wolsink, 2018). Therefore, the stakeholders can help to answer the essential question: where and what kind of energy-scape elements to establish.

Especially, this constitutes a crucial point for development of new renewable energy installations and infrastructure necessary for low-carbon cities and urban energy transition. There are important barriers of renewable energy technologies penetration. The technological obstacles may hinder the intake of renewable energy (technologies). These obstacles include inadequate infrastructure or lack of energy storage capacity. These infrastructure barriers are key for renewable energy projects in urban areas. Infrastructure necessary for renewable energy projects is very costly as includes financing of additional transmission lines necessary to connect renewable energy plants to the grid and storage technologies.

Usually, due to social barriers of renewables like NIMBY (an acronym of the term “Not In My Back Yard”) syndrome, people are against installation of renewable energy plants or energy storages next to their homes. The proposed framework allows to understand better they fear and to prove the insignificant impact of renewable energy technologies and infrastructure including energy storage facilities on environment and public health. The involvement of various stakeholders in the decision-making allows to boost social acceptance of new technologies development and increase the concern of the environment. It can also serve in the development of future energy projects and can increase concern about energy efficiency. Also, this framework is very useful for decision-making where the appropriate infrastructure should be located as public acceptance is key issue in development low-carbon communities, cities and societies.

5 Conclusions and policy recommendations

The transition to low-carbon energy society rises numerous intertwined choices over development of infrastructure and specific technologies. The installed capacity of renewables has seen a significant upturn in the last decade all over the world. Renewables are a cornerstone in meeting the global energy needs along with ensuring climate change mitigation. The term of energy-scape encourages discussion about interactions between the energy system and the environment, and other ecosystem services at local level.

Nowadays, the energy market faces a lot of challenges. The global energy crisis in the context of the COVID-19 pandemic and global economic uncertainty due to Russia’s invasion of Ukraine confirmed that the dependence on imported energy sources may have significant negative consequences. Individual and commercial energy consumers face the multiple negative effects such as rising energy poverty, the decrease in quality of life, rising prices for final products and services, cost growth, and profit reduction. The development of new renewable energy infrastructure is the main measure to ensure energy security and energy independence in both country and individual level. Therefore, the much
more significant effort should be made to encourage fast development of new renewable infrastructure.

The literature review identified the major challenges and bottlenecks related to the transition towards low-carbon energy society. The main contribution of the paper to the existing literature is the creation of framework for the analysis and assessment of new renewable energy technologies installation and infrastructure. The major points pertinent to installation of the renewables have been identified to support the decision-making. The presented framework can be applied for all technologies and allows to achieve a decision on creation of low-carbon cities and urban energy systems acceptable to the local community.

This developed framework is very useful for selection of policies and measures necessary for low-carbon energy transition. Specifically, it allows to evaluate policies based on their impact on the main relevant areas such as economic, social and environmental including landscape, ecosystem services. Although the development of clean technologies in households is more and more increasing and the public perception regarding clean micro-generation technologies is also growing, there are still significant challenges when it comes to large energy projects. First of all, it should be widely accepted practice at political level that the selection of possible location for new large renewable infrastructure should begin with an assessment of the impact on ecosystem services. This would ensure the continuity of ecosystem services. The involvement of relevant stakeholders is also crucial to ensure the participatory approach. Based on stakeholder involvement, a context-specific issue of low carbon transition can be solved that reflects the relevant challenges and priorities of these stakeholders. Thereby, public acceptance of the decisions related to low-carbon energy transition can be increased.

The paper has limitations as this theoretical paper and energy-scape including developed framework needs to be applied for selected local community in order to show its applicability for decision-making and public involvement in creation of low-carbon communities and development of urban energy systems. The future research will present the case study of assessment of new renewable energy technologies installation and infrastructure for selected community in Lithuania.

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