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Challenges to the low carbon energy transition: A systematic literature review and research agenda

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ABSTRACT

Many challenges should be tackled in transitioning to a low-carbon energy system, motivating many researchers to study these challenges. In this context, the present study aims to identify challenges through a systematic literature review of studies published between 2006 and 2023 to propose a comprehensive framework of challenges. To this end, the PICOC framework was applied to set the research scope properly; and an integrated method called PSALSAR protocol was used to find, evaluate, and review publications published in Scopus and the Web of Science. As a result, 123 articles were reviewed, and seventeen challenges were identified and classified into five social, economic, environmental, technical, and institutional challenges. Results indicated that international agreements on climate change could boost the number of studies on the low-carbon energy transition. Also, it is indicated that researchers applied qualitative methods more in earlier studies, and methods and topics have become more profound over the years.

1. Introduction

The energy sector is the leading contributor to greenhouse gas (GHG) emissions, making the low-carbon energy transition a global trend [1] since GHG emissions affect global warming and climate change, the most important issues globally. Transition to a low-carbon energy system is a reaction to the dual challenges of sustainable development and climate change, requiring rapid and radical socio-technical changes [2–4]. For instance, according to the Paris agreement, a global 60%–80% reduction in GHG emissions by 2050 needs the broad adoption of low-carbon products and services, including hybrid, hydrogen fuel cells, low-energy automobiles, and residential solar panels. Furthermore, several agreements and agendas on global and local scales have been adopted, including the Paris agreement and the 2030 agenda for sustainable development, in which low (zero)-carbon energy is the primary goal [5–7]. Therefore, many countries look for renewable and sustainable alternatives to current energy systems owing to the growing energy demand, CO2 reduction, the dwindling reserves of fossil fuels, and climate change [8,9].

Also, the Fifth Assessment Report (AR5) of the United Nations' Intergovernmental Panel on Climate Change (IPCC) emphasizes the need for nations to find alternatives to fossil fuels. The IPCC advises that by 2050, at least 80% of the world's energy supply should be renewable to avert some of climate change's most catastrophic impacts [10]. However, despite the international confidence expressed in the Paris agreement, energy policies have failed to deliver equitable and effective carbon reductions at all levels since several challenges stemming from economic, social, environmental, technical, political, and institutional challenges. Therefore, to overcome these challenges and to keep global warming far below 2°, international, national, and local authorities, researchers, and communities must work on all fronts [11,12]. To this end, many researchers have studied challenges to low carbon energy transition over the years as academics worldwide play a critical role in facilitating the energy transition [13,14].

For instance [15], have studied the energy transition in Canada and concluded that public education is one of the crucial factors affecting the energy transition; it boosts public awareness and engagement. Also, Baran et al. (2020) have investigated the low-carbon energy transition from a labor market perspective in coal-based countries, and they concluded that even if all new jobs in green industries would be filled by workers who used to work in coal-based sectors, there is still a gap in the job market. Stavrakas [10] have also investigated the barriers to low-carbon energy transition in Greece and the consequences of adopting renewables. They concluded that Gross Domestic Product (GDP) and labor productivity would temporarily decrease during the energy transition; however, investments in Renewable Energies (REs)

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could affect the duration and intensity of the transition's effects. Also, Nochta and Skelcher (2020) conducted a comparative analysis across the EU to investigate the role of the states in the low-carbon energy transition; they concluded that budget constraints could affect the public sector's capacity to boost climate change adaptation and mitigation.

Moreover [16], has investigated environmental justice and conflicts in wind energy as environmental challenges of the low-carbon energy transition. The results indicated that land acquisition is one of the distinguished aspects of the global land rush, changing land-use patterns. Also, Seck et al. (2020) investigated the interactions between supply limitations and low-carbon energy transition. They concluded that demand-control measures should accompany the massive growth in copper consumption, and copper recycling industries should not jeopardize energy production. Also, Goldthau and Westphal (2019) have investigated short-termism in petrostates as an institutional challenge. They concluded that petrostates prefer short-term income even if it affects their long-term income from oil production since short-termism is crucial for their political positions. Also, Kuamoah (2020) has investigated REs adoption in Ghana under the Sustainable development Goals (SDGs). The results indicated that one of the barriers to low-carbon energy transition is the lack of infrastructure, considered a technical challenge, especially unstructured energy grids.

As there are many challenges to the low-carbon energy transition, it would be challenging to follow climate change agreements and agendas at the necessary pace. On top of that, The low-carbon energy transition is a socio-technical transition that simultaneously requires dealing with many challenges, barriers, and issues [17]. Therefore, there is a need for a comprehensive framework in which challenges to the low-carbon energy transition are presented in detail to assist decision-makers in dealing with challenges by improving the required knowledge around challenges and solutions founded by researchers over the years. Furthermore, researchers need to know the current status quo of the challenges to the low-carbon energy transition to move forward. Therefore, the present study aims to conduct a systematic literature review to assist academics and authorities in dealing with the low-carbon energy transition. To this end, the Protocol, Search, Appraisal, Synthesis, Analysis, and Report (PSALSAR) framework is applied to review the literature from 2006 to 2023. Subsequently, the framework of Population, Intervention, Comparison, Outcome, and Context (PICOC) is employed to set the research scope. The main contributions of the present study are presented in the following.

- To propose a comprehensive framework of challenges to the low-carbon energy transition. A comprehensive framework helps identify and address the barriers and obstacles hindering the low-carbon energy transition. By understanding and tackling these challenges, policymakers and stakeholders can devise effective strategies to accelerate the transition. Also, By understanding the specific challenges, researchers and technology developers can focus on developing solutions that directly address the critical issues faced during the transition.
- To review applied methods for dealing with the low-carbon energy transition challenges. By reviewing the methods and strategies that have been previously applied, policymakers and stakeholders can learn from both successful and unsuccessful experiences. Also, The energy transition is a complex and evolving process. Regularly reviewing the methods helps in identifying areas that require improvement and adjustment. This iterative process enables the implementation of more effective solutions over time, ensuring the transition stays on track and adapts to changing circumstances.
- To illustrate the distributions of studies considering publication year and journals. By plotting the distribution of studies based on publication year, researchers and policymakers can identify trends in the number of publications over time. It helps in understanding the growth of interest in the low-carbon energy transition, the rate of research output, and whether there are any significant spikes or lulls in research activity. Also, Journals' reputations and impact factors can indicate the influence and visibility of the research published in them. Analyzing the distribution of studies across journals can help researchers understand the reach and impact of their work and others in the field.
- To provide a research agenda according to the future research directions given by researchers. A research agenda aligned with their identified future research directions helps prioritize addressing these critical gaps, ensuring that research efforts are focused on areas of maximum impact. Also, incorporating researchers' insights makes the research agenda more relevant and practical. It ensures that the research questions and objectives align with real-world challenges and needs, increasing the likelihood of producing actionable findings and applicable solutions.
- To provide policy recommendations based on reviewed articles. Policy recommendations grounded in reviewed articles provide policymakers with evidence and data-driven insights. It helps ensure that policy decisions are based on reliable information and research findings rather than opinions or assumptions. The policy recommendation is crucial in ensuring that policy decisions are well-informed, evidence-based, and aligned with international goals. By drawing on the knowledge in peer-reviewed literature, policymakers can design effective, efficient, and sustainable policies to accelerate the transition to a low-carbon energy future.

The remainder of the present study is as follows: section 2 presents the integrated research method for identifying, refining, and selecting publications within databases. Section 3 investigates the distribution of the papers through tables and charts. A comprehensive model is proposed and discussed in section 4. Section 5 provides conclusions, future directions, and research limitations.

2. Research method

The SALSA, search, appraisal, synthesis, and analysis, a framework is used to search and analyze the literature. The technique enables a thorough literature review while minimizing the possibility of subjectivity [18–20]. The SALSA technique is recognized in the scientific literature as an effective instrument for finding, analyzing, and systematizing scientific and practical investigations. It also ensures the work's methodological accuracy and completeness [20]. Additionally, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement assures the uniformity and thoroughness of research [21]. The PRISMA statement comprises a 27-item checklist and a four-phase flow diagram, including identification, screening, eligibility, and included papers [22–25]. However [26], proposed a new approach by integrating PRISMA and SALSA, abbreviated as PSALSAR, which has six main steps: Protocol, Search, Appraisal, Synthesis, Analysis, and Report. The present study employs an

Table 1
Methodology for systematic literature review.

Steps	Tasks	Approaches
Research protocol	Study scope: identifying the challenges to the low-carbon energy transition	The PICOC
Searching	Searching for publications related to the research goals	Searching in Scopus and Web of Science (WOS) using specific keywords
Appraisal	Selecting eligible studies	The PRISMA protocol
Synthesis	Classification information extracted from included articles	The PRISMA: a 27-item checklist
Analysis	Analyzing the classified information and proposing a novel framework of challenges	The PRISMA: a 27-item checklist
Report	Summarizing the results of analyses in the form of an article	The PRISMA: a 27-item checklist

integrated PSALSAR technique. Table 1 presents the methodology for conducting a systematic literature search to identify low-carbon energy transition challenges.

Step 1. **Research protocol**. It contributes to the literature evaluation's transparency, reproducibility, and systematic character and reduces subjectivity in the study undertaken. The critical objective at this stage is to specify the scope of the present research. Research questions may be developed, and the most relevant strategies for accomplishing the study aim can be chosen. The PICOC framework is an effective tool for defining the scope of research, which was employed in this study. The framework establishes a rigid structure that enables an examination of the research questions in terms of their constituent ideas, defining the study's purpose [20,27]. Table 2 summarizes the PICOC framework used in the present study.

The main research questions are presented in the following.

1. What impediments and obstacles are encountered in implementing the low-carbon energy transition?
2. What methodologies are employed to address the challenges to the low-carbon energy transition?"
3. What are the main research gaps in the low-carbon energy transition context?

Step 2. **Searching**. It entails developing and implementing a search strategy. It is critical to select the appropriate database to ensure that the literature obtained is of good quality and represents the majority of papers accessible. To this end, all articles indexed on Scopus and Web of Science have been found by the following research strings:

Scopus: TITLE-ABS-KEY (("low carbon energy transition") OR ("low carbon transition") OR ("green energy transition") OR ("just energy transition") OR ("renewables" AND "energy transition")) OR ("challenge" AND "renewable" AND "energy transition"))

WOS: All=((low carbon energy transition) OR (low carbon transition) OR (just energy transition) OR (green energy transition) OR (renewables AND energy transition) OR (renewables AND energy transition) OR (challenge AND renewable AND energy transition))

Step 3. Appraisal. The selected articles have been evaluated considering the present research aims; thus, only publications meeting the search requirements are selected using the PRISMA protocol. The following requirements apply to inclusion: firstly, search keywords should be in the title, abstract, or keywords, and secondly, articles should be published in a scientific peer-reviewed journal. Also, the following requirements apply to exclusion: editorial letters, chapter books, review papers, academic theses, conference proceedings, duplicated publications, and non-English language studies. Fig. 1 indicates the research information flow.

Table 2
The PICOC framework for justifying the research scope.

Concept	Definition	Application
Population	Studies on challenges to the low-carbon energy transition	Articles in which a novel methodology, conceptual framework, etc., were applied to cope with at least one of the challenges to the low-carbon energy transition
Intervention	The status quo of challenges to the low-carbon energy transition in the world	Giving a complete picture of the challenges to the low carbon energy transition and methodologies to deal with them
Comparison	Highlighting a specific challenge, not a broad picture	Developing policies to deal with a particular challenge to the low-carbon energy transition
Outcome	Challenges and sub-challenges to the low-carbon energy transition	A comprehensive framework of challenges to the low carbon energy transition, which includes all social, environmental, institutional, and environmental aspects
Context	Finding the various features included in the low carbon energy transition studies	Challenges, methodologies, future directions, gaps, and aims of studies

Step 4. **Synthesis**. The extracted information has been classified into general and specific categories. The publication year, journals, case study location, and future directions were general information, while research gaps, aims, results and methodologies addressed challenges, and their type was specific information that addressed the research questions. The identified challenges were classified into social, economic, environmental, technical, and institutional.

Step 5. **Analysis**. This stage seeks answers to the core research questions and analyzes the categorized data concerning the research requirements. The results of this stage are presented in section three.

Step 6. **Report**. This step entails the presentation of critical points stemming from step 5. The PRISMA statement's 27-item checklist presents the literature review outcomes.

3. The status quo of the low-carbon energy transition

Many journals and publishers have contributed to extending the low-carbon energy transition. According to the results, "Energy Research & Social Science" has contributed the most to the literature with 15 published articles, followed by "Energy Policy" with 12 published articles. The distribution of the journals based on the published article is shown in Fig. 2.

Moreover, the distribution of articles based on the publication year shows a growing interest in studying the low-carbon energy transition after 2016; 24 articles were published in 2020, and most were published yearly. Fig. 3 illustrates the distribution of papers based on publication year.

2.1. Publications between 2006 and 2015

All articles published over a decade before the Paris agreement are discussed in Table 3. The number of published articles addressing challenges was not high before the Paris agreement. The studies published over this period tried to find the relationship of the energy

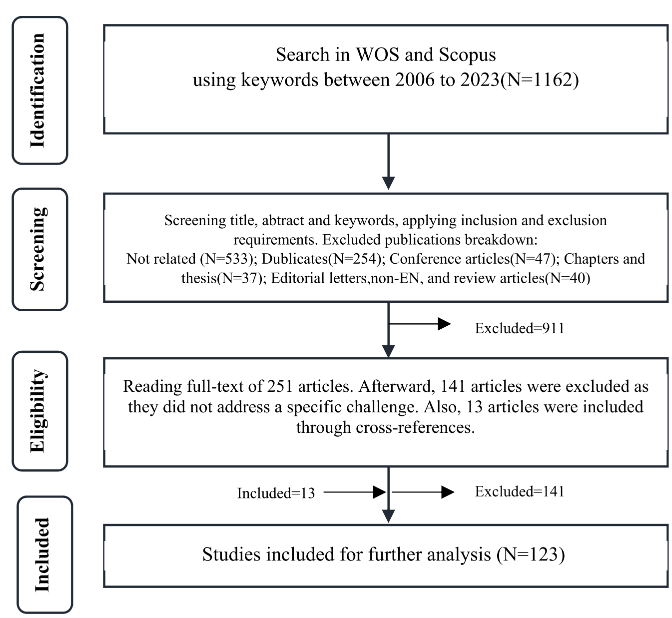

Fig. 1. Research information flow.

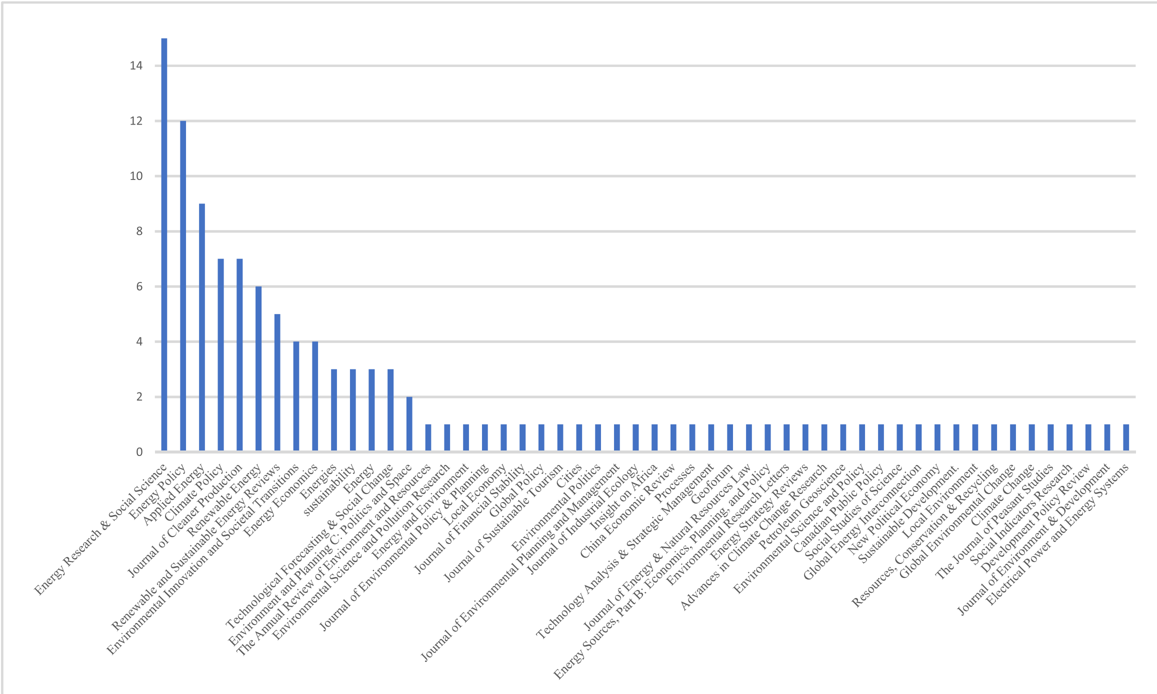

Fig. 2. Distribution of journals based on published papers.

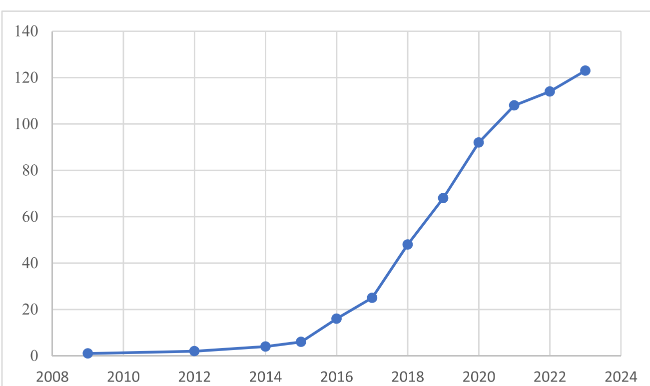

Fig. 3. Distribution of papers based on publication year (cumulative).

transition with other concepts in the energy sector, such as energy security.

2.2. Studies published in 2016

The Paris agreement was ratified in 2016, impacting the number of studies in this field. Most of the studies employed qualitative methods as they are more useful when there is no solid background on a specific topic. Table 4 discusses the published articles in 2016.

2.3. Studies published in 2017

Studies in 2017 also employed more qualitative methods; however, the footprint of quantitative and comparative methods could be seen in this period. Also, European countries conducted more studies this year. Table 5 presents the published articles in 2017.

2.4. Studies published in 2018

Many quantitative methods, such as the agent-based model, Monte Carlo, regression analyses, and fuzzy methods, were employed in 2018. However, some studies also applied qualitative methods, such as content analysis. Table 6 presents the published articles in 2018.

2.5. Studies published in 2019

More complex methods were applied in 2019 to deal with various research gaps related to the low-carbon energy transition; however, researchers applied more quantitative methods than qualitative ones. Table 7 presents the published articles in 2019.

2.6. Studies published in 2020

Many valid and complicated mathematical methods, such as the multi-level perspective (MLP) or Computable general equilibrium, were proposed and applied by starting a new decade. Also, Chinese researchers contributed more compared to before. The highest number of articles related to this field was published this year., Table 8 presents the published articles in 2020.

2.7. Studies published in 2021

Comparative and content analyses were applied more in 2021, primarily by Chinese researchers. Also, researchers studied more on just energy transition, trying to focus more on the social consequences of the low-carbon energy transition. Table 9 presents the published articles in 2021.

2.8. Recent studies published in 2022-23

The footprint of Covid-19 could be seen in recent studies, and quantitative approaches were applied more, primarily by researchers from China. The applied methods and topics are more profound than the earlier studies. Table 10 presents published articles in recent years, 2022–2023.

Table 3
Publications between 2006 and 2015.

Author (s)	Methods	Research gap	Study aims	Case study location
[28]	PowerPlan model, Long-range Energy Alternatives Planning model (LEAP), and Regional Energy Model (REM)	Need to implement low-carbon energy technologies in China and India as they are dependent on fossil fuels	the implications of low-carbon energy transitions in China and India	China and India
[29]	Social network analysis (SNA)	Need to change customer behavior to approach low carbon energy transition	To study the effect of social influencers on customer behavior related to the low-carbon energy transition	–
[30]	Autoregressive moving average (ARMA)	Need to understand whether a low-carbon-energy transition could be sustained after the Fukushima accident.	To analyze various exogenous shocks' impacts on electricity consumption	Japan
[31]	Qualitative Comparative Analysis	Need to investigate the low-carbon energy transition challenges	To investigate the relationship between energy security, technology scale, and decarbonization in the UK	UK
[32]	Qualitative Comparative Analysis, interviews	Need to understand the governance strategies for transition	To investigate the uncover governance challenges associated with the low-carbon energy transition	UK
[33]	Linear programming	Lack of studies that assess emerging countries' progress toward low-carbon energy transition	To evaluate the decarbonization strategies in Nicaragua for 2014–2030	Nicaragua

3. Challenges to the low-carbon energy transition

The present study classified challenges into five classifications and proposed a framework of challenges to the low-carbon energy transition. The five pillars of the proposed framework are explained below. Afterward, each identified challenge is explained in detail.

- Social pillar: challenges classified in this pillar directly affect people or are affected by them. For instance, public acceptance is a critical challenge to the low-carbon energy transition, which is closely connected to public engagement; therefore, stakeholders, including governments, should boost public acceptance by increasing public engagement. Also, public awareness affects any social transition, including low-carbon energy transition. There is an interconnection between public awareness and education, meaning improving public education could boost awareness. However, resistance to change is another barrier to any social transition due to the lack of awareness and engagement, which causes changes in consumer behavior. Also, the low-carbon energy transition might affect the revenue of those

Table 4
Studies published in 2016.

Author (s)	Methods	Research gap	Study aims	Case study location
[34]	Qualitative Comparative Analysis	The Transition Policies to sustainable energy have the potential for democracy; however, there is not enough debate.	To bring low carbon energy transition theory into conversation with relational and constructivist Science and Technology Studies on public participation	UK
[35]	Qualitative Comparative Analysis	Need to investigate the civic ownership structures and interplay of financial institutions.	To compare the emerging civic energy sectors in two countries to find the enabling role of financial institutions	UK, Germany
[36]	Qualitative Comparative Analysis	Need to investigate the relationship between low-carbon energy transition and the global geography of power.	To bridge three insights, including socio-technical transitions, energy geographies, and the rising powers as (re) emerging development donors	Mozambique and South Africa
[37]	Qualitative Comparative Analysis, Interviews	Need to investigate the relationship between low-carbon energy transition and political structure.	To study the impact of neo-liberalization and low-carbon energy transition	Kenya
[38]	Scenario planning	Need to investigate the low-carbon energy transition challenges.	To examine the low-carbon energy transition development through various scenarios in China	China
[39]	Qualitative Comparative Analysis	Need to analyze the effect of structural factors affecting low carbon energy transition.	To investigate the low carbon energy transition policies in two countries labeled as two opposite forms of capitalism	Germany and UK
[40]	Qualitative Comparative Analysis	Need to study where urban low-carbon energy transitions are governed.	To investigate how various governance processes are integrated to boost urban low-carbon energy transitions.	Norway
[41]	Mathematical model and scenario planning	Need to investigate the investment risk in low-carbon technologies.	To study the perceived risks' impacts on electricity prices from semi-dispatchable concentrated solar power	Algeria, Egypt, Morocco, and Tunisia

(continued on next page)

Table 4 (*continued*)

Author (s)	Methods	Research gap	Study aims	Case study location
[42]	Qualitative Comparative Analysis	Need to investigate the potential conflicts between low-carbon energy transition and long-term environmental policies.	To identify practical government arguments in Sweden which could reduce the conflicts between low carbon transitions and long environmental policies concerning EQOs	Sweden
[2]	Qualitative Comparative Analysis and literature review	The lack of studies on the role of institutions in the low-carbon energy transition.	To show the advantages of applying a more comprehensive set of institutional theories to the low-carbon energy transition' studies	China, Germany, and the UK

stakeholders who profit from the current system. Moreover, job loss and creativity are two essential side-effects of each social transition, including the low-carbon energy transition. The created jobs in green industries should adequately fill the gap caused by the low-carbon energy transition in the labor market; otherwise, the transition might face serious resistance due to the high numbers of high job loss, especially in highly dependent industries to fossil fuels. Furthermore, the low-carbon energy transition should guarantee secure and affordable energy. Energy poverty is one of the global challenges in the energy sector which should be addressed. A just energy transition is a crucial solution to energy poverty, motivating the present study to include energy justice in the proposed framework.

- Economic pillar: it comprises challenges to the low-carbon energy transition affecting investment in the energy sector, creating competitive advantages, and stimulating economic growth. For instance, all stakeholders should consider investment risk in any socio-technical transition, including low-carbon energy transition. The low-carbon transition might temporarily decrease labor productivity and GDP, but these effects' time duration and intensity depend on the investment amount. Low-carbon transition requires a considerable investment since it requires severe shifts in current technologies, standards, and customer behavior. As a result, governments should provide incentives, such as subsidies, for investors to increase their contributions. Although energy subsidies might boost low-carbon energy development, they might be a barrier to the low-carbon energy transition since governments still give considerable subsidies on fossil fuels to secure energy accessibility. Furthermore, energy transition costs should be addressed as severe challenges to the low-carbon energy transition, including adaptation and mitigation costs. Mitigation costs refer to spending for reducing GHG emissions, and Adaptation costs refer to spending for building a more resilient society to climate change.
- Environmental pillar: it comprises challenges affecting climate change, environmental pollution, natural resources consumption, and land use. A severe challenge to the low-carbon energy transition is resource consumption, such as sand consumption for building green and energy-efficient buildings or lithium, selenium, gallium, cadmium, tellurium, and germanium used in energy storage and solar photovoltaic panels. On the other hand, landfills for waste management and land use on a massive scale for building solar and wind farms are critical challenges to the low-carbon energy transition. For instance, green grabbing is a new form of land acquisition in which land and natural resources are dispossessed under sustainable development goals. Also, recycling lithium-ion batteries would not be a pollution-free activity; pyrometallurgy is a high-energy process that generates GHG emissions and poisonous fumes, and its hazardous waste must be landfilled.

Table 5
Studies published in 2017.

Author (s)	Methods	Research gap	Study aims	Case study location
[43]	Regression analyses	Lack of study on phase-out policies for the low-carbon energy transition.	To investigate Germany's nuclear phase-out policy's effect on renewable power generation technologies.	Germany
[44]	Qualitative Comparative Analysis	Need to elaborate on the energy constitution concept.	To study the energy constitution in the UK and how it affects low-carbon energy transition.	UK
[45]	Survey	Need to deal with the high cost of investment in transition.	To propose a new theory to replace the neoclassical notions of investment and capital market	UK
[46]	Comparative analyses	Need to Democratize energy system transitions.	To propose an accurate picture of the impacts of (in)justice on low carbon energy transition	–
[47]	Qualitative Comparative Analysis	Need sustainable pathways toward low-carbon energy transition.	To analyze three groups of low-carbon transition methods	–
[48]	Qualitative Comparative Analysis	Need to develop strategies for having fossil-free energy systems.	Study how Nordic countries want fossil-free energy systems by 2050 and the challenges.	Nordic countries
[49]	Survey	Need to develop new supportive policies.	To propose approaches for developing comprehensive policies	–
[50]	Survey and interview	To bridge the gap between techno-economic and societal disciplines and theory and practice in energy futures research.	To study which type of decarbonizing is preferable: centralized or decentralized	Germany
[51]	linear programming	Need to study how solar photovoltaic (PV) could boost energy access in an eco-friendly and affordable manner.	to investigate strategic directions and their impact on global energy sustainability through solar PV	India, Nigeria, Congo, Bangladesh, Ethiopia

Table 6
Studies published in 2018.

Author (s)	Methods	Research gap	Study aims	Case study location
[52]	Qualitative Comparative Analysis	Need to study causal inferences and community Perspectives concerning perceived energy (in) justice.	To analyze low carbon energy transition considering the justice concept	Denmark, Germany
[53]	Content analysis	To study the gap between energy transition and energy security	To propose a decision support system concerning energy security and energy transition	South Africa
[54]	Theoretical approach	Need to study the effect of policies on low-carbon energy transitions	To study alternative pathways for disruptive risks stemming from policies' risk concerning variable renewable electricity (VRE)	Finland
[55]	Comparative analyses	Need governmental support in the low-carbon energy transition	To investigate how governmental support could affect energy transition	China
[56]	the survey and interview	Need to study the roles of citizens and public engagement in the low-carbon energy transition.	To link energy citizenship to developments in Science and Technology Studies (STS)	Denmark
[57]	Interviews	The tourism sector should reduce its CO_2 emission	To figure out the tourism sector's understanding of the decarbonization challenge	–
[58]	Descriptive statistic	Need to consider energy justice in transition	To introduce energy justice considering the federal policies in India	India
[59]	Statistical Method	Need to study Nordic countries' experiences in the low-carbon energy transition to get lessons.	To investigate low carbon energy transitions in the Nordic countries for four decades, considering the Environmental Kuznets Curve (EKC)	Nordic countries
[60]	Mathematical model and scenario planning	Need to study the various technologies applied in the decarbonized energy system	To evaluate the applicability of marine energy compared to other technologies in the UK	UK
[61]	The employment factor approach, CGE models	Need to study the effect of the energy transition on the labor market	To study net employment impacts from energy transition in the EU	EU
[62]	fuzzy cognitive map (FCM), dynamic stochastic general equilibrium (DSGE) model, Business Strategy Assessment Model (BSAM)	Need to study the possible uncertainties in transitions	to study the barriers to low carbon transitions in Greece	Greece
[63]	Qualitative study: individual and group interview	Need to develop new political paradigms for the low-carbon energy transition.	To investigate how renewable industries should be promoted in China concerning the up-down approach.	China
[64]	Qualitative Comparative Analysis, Interviews	Need to analyze low carbon transition based on a justice perspective	To study how finance shapes the justice energy transitions outcomes and how energy policy shapes these justice outcomes	UK-Germany
[65]	Linear regression model	Need to know policy credibility is formed	To investigate whether understanding of policies' credibility depends on the current policy mix	Germany
[66]	Theoretical approach	Need to study the local and governmental support in the transition	To propose a framework of contributions to the low-carbon transition	Cologne
[67]	"Price-gap" approach	Need to remove the subsidies to move toward low carbon energy transition	To study the effect of removing fossil fules' subsidies on energy transition	China
[68]	Agent-based model and Monte Carlo	Need to evaluate the investment risk	To develop a model for assessing the impacts of investment on the development of an energy system	China
[15]	Qualitative Comparative Analysis	Need to investigate how low carbon energy transition will unfold in Canada	To examine the features of transition experiments	Canada
[69]	Linear programming	Need to transform from current coal-fueled systems to low-carbon energy systems.	To propose a transition plan to shut down the current system and integrate REs into the grid.	–
[70]	MESSAGE, Scenario planning	Need to study the current uncertainty in the future costs of large-scale variable renewable energy (VRE)	To investigate future storage implications and costs of hydrogen technology for low-carbon energy transitions	–
[71]	Linear programming	Need to study transmission investment as a critical element in the low-carbon energy transition.	To propose a hub based on transmission investment strategy for countries in a region	Romania-Turkey

Table 7
Studies published in 2019.

Author (s)	Methods	Research gap	Study aims	Case study location
[72]	Hypothetical Extraction Method (HEM)	Need to study the effect of the energy transition on the labor market	To apply a hypothetical model to address the neglected impacts of the energy transition on the labor market	UK
[73]	Semi-Structured Interview	Need to investigate energy justice in transition	To study the level of injustice in four European energy transition	Germany, France, the UK, and Norway
[74]	Mathematical model	Need to study the investment uncertainty	To propose a model to deal with investment uncertainty	China
[75]	"Price-gap" approach	Need to remove the subsidies to move toward low carbon energy transition	To study the effect of the metallurgical industry's subsidies on energy transition	China
[76]	NET-Power model	Need to evaluate the pathways of energy transition	To develop six scenarios for energy transition considering the transition cost	China
[77]	The survey, Qualitative Comparative Analysis	Need to transform common lands into solar parks	Investigate the economic and political procedure of transforming common lands belonging to agropastoralists into solar lands.	India
[78]	Real Options Analysis	Need to identify the challenges to the low-carbon energy transition	to conduct a quantitative analysis of investment barriers to the energy transition	Russia
[79]	Semi-Structured Interview	Need to investigate energy justice in transition	To study injustice types in four European energy transition	Germany, France, the UK, and Norway
[80]	TIMES Framework, scenario planning	Need to evaluate the various pathways to achieve a low-carbon energy system	to study the role of bioenergy in the low-carbon energy transition	Canada
[81]	MCDA	Need to analyze the current status of low-carbon energy transitions in Vietnam.	To review the publications to find criteria and apply MCDA to rank developed polices	Vietnam
[82]	Qualitative Comparative Analysis	Need to investigate the paradox between short-term policy and low-carbon energy transition.	To conceptualize a framework for temporal energy justice	India
[83]	EIRIN model	Need to remove the subsidies to move toward low carbon energy transition	To study the effect of removing fossil fuels' subsidies on energy transition	–
[84]	Mathematical model and scenario planning	Need to study building retrofitting as one of the factors affecting low-carbon energy transition.	To propose a decision support system to evaluate the energy efficiency measures' profitability	Spain
[85]	Qualitative Comparative Analysis	Lack of connection between circular economy and low carbon energy transition	To link circular economy to low carbon energy transition through non-energy use (NEU)	–
[86]	LEAP-Linear programing	Need to analyze various transitions scenario	To propose a forecasting model to analyze the transition scenario	Botswana
[87]	Agent-Based Model	Need to understand the possible energy transition pathways	To integrate human behavior with energy systems using an agent-based model	–
[88]	multi-level perspective approach (MLP)	Need to study the possibility of transitions toward a sustainable future	To analyze Res in Bulgaria over ten years	Bulgaria

- Institutional pillar: It comprises challenges affecting decisions, policies, and strategies or is caused by them. Although socio-technical transitions require new supportive policies, anti-innovation policies might hinder the low-carbon energy transition, similar to public resistance to change and investment risks. For instance, the wind turbine industry requires domestic market demand and research and development support, or export-oriented manufacturing policies are vital for PV manufacturing. Also, short-term policies are barriers to the low-carbon energy transition. For instance, countries with enriched non-renewable resources tend to give more energy subsidies to support their political parties; however, low fossil-fuel prices impact the pace of the low-carbon energy transition. Furthermore, reformation and transition are two faces of a coin; thus, reformation is required for a successful low-carbon energy transition; however, reformation might cause conflicts and, subsequently, resistance to changes. Constant conflicts throughout the policy development stages are possible, such as conflicts in determining tariffs, affecting investment returns.
- Technical pillar: It comprises challenges influencing infrastructures, technology development, and technical standards. The technical shift is inevitable in the low-carbon energy transition to affect the global energy budget on climate change, sequester carbon emissions, and reduce or stabilize the global average temperature. As a result, sustainable energy systems are jointly approaching standards, technology, and infrastructure. For instance, some Technical changes that should be implemented are adopting low-carbon technologies to improve energy efficiency at the production level and energy saving on the demand side. However, a lack of Technical standards could hinder the developing and adopting of new low-carbon technologies at the desired pace, meeting local and global requirements according to international agreements, such as the Paris agreement.

Table 8
Studies published in 2020.

Author (s)	Methods	Research gap	Study aims	Case study location
[89]	Qualitative Comparative Analysis-network visualization	To study the effect of network governance on low-carbon transition and transition management (TM)	To compare energy transition networks in three countries	UK, Germany, Bulgaria
[90]	Qualitative study: individual and group interview	Need to investigate the political aspects of low-carbon energy transition	To employ a political framework to investigate the unfolding transition politics in new energy vehicle (NEV) development	China
[91]	dynamic simulation model, scenario planning	Need quantitative analysis to provide a decision-support system for policymaking.	To study the energy strategy concerning the low-carbon energy transition (2016–2030)	China
[92]	the multi-level perspective (MLP) and agent-based modeling (ABM)	Need to propose a theoretical and practical framework for the low-carbon energy transition process	To apply two new methods for a detailed and more profound analysis of low-carbon transitions	–
[93]	A mathematical model named CRESOM	Need to find the best transition pathway	To analyze and find the proposer pathway for the low-carbon energy transition	China
[94]	Interview and survey	Need to investigate energy justice in transition	To integrate energy justice into the energy transition project in China	China
[95]	Mathematical models and scenario planning	Need to cope with the targets of climate change mitigation	To provide some pathways and identify the challenges to low carbon transition	China
[14]	Qualitative Comparative Analysis, interviews	Need disruptive innovation to increase the speed of transition	To bridge disruptive innovations and system-level transitions' concept	UK and Germany
[96]	Static and Dynamic Panel	Need to study the effect of public investment	To study the effect of public investment in 17 countries	–
[97]	Scenario planning	The low-carbon infrastructure needs sand which is a limited resource	To map the projected investments in low-carbon infrastructure	–
[98]	Computable general equilibrium (CGE) model	Need to evaluate the risk of the low-carbon transition	To assess the implementation risk of energy transition in the steel and electricity sectors	Austria
[99]	Cluster analysis approach	Need to study the social acceptance of the low-carbon energy transition	to identify energy visions toward low carbon energy transition	UK
[100]	Global Change Assessment Model (GCAM) model, Scenario planning, survey, and interview	The environmental, social, technical, political, and economic risks of low carbon energy transition must be investigated.	To explore the barriers between scientists and stakeholders concerning climate change alleviation aspects	USA, EU27, Canada, Japan
[11]	Qualitative Comparative Analysis, interviews	Need to have pathways for low-carbon energy transitions	To draw a pathway for energy transitions in Spain and develop guidelines for its future	Spain
[101]	mixed-integer linear programming (MILP) model	Need to optimize the storage systems	to analyze the possibility of installing new renewable energy plants	Italy
[8]	Survey	Need to investigate the potential of energy transition	To analyze the current situation of the energy sector in Ghana	Ghana
[102]	multinomial logit model (MNL)	There is no comprehensive evaluation of citizens' potential to co-finance	To investigate the European tendency for investment in the low-carbon energy transition	EU28
[13]	Case study	Need to understand how low-carbon energy transition could be enabled through REs.	To study the contribution of the helix mechanism to the future electricity system	Greece
[103]	scenario-based analysis	The climate change policies' impacts on North Africa's current energy system must be simulated.	to evaluate the energy transitions' sustainability in the North African economies	North Africa
[104]	LEAP	Need to study long-term planning and forecasting of energy demand and supply.	To propose a forecasting model and evaluate various scenarios for the energy sector in Chile	Chile
[105]	linear programming	Need to determine Cooper's impact on the low-carbon energy transition.	To propose a mathematical model to evaluate the copper availability due on 2050	–

3.1. Social challenges

In the following, social challenges are presented in detail, including public acceptance and engagement, public education and awareness, behavior changes and resistance, energy justice, labor transition, and energy security.

Public acceptance and engagement. The role of states in increasing engagement transition processes was not addressed adequately [138,139], and the critical role of public and democratic engagement in low-carbon energy transition has been disregarded in many studies [34,140]. Widespread public acceptance is vital to promote an energy transition toward a low-carbon system [15,87]; also, public engagement increases the reliability of low-carbon technologies and, in general, the acceptability of low-carbon energy transition [13,141]. Behavioral change is needed for public acceptance, stimulating

Table 9
Studies published in 2021.

Author (s)	Methods	Research gap	Study aims	Case study location
[106]	Survey and interviews	Need to deal with injustice transition	To analyze consumers and energy injustices in three low-carbon transitions	Germany, Norway, Great Britain
[1]	Comparative analyses	Need to consider justice in transition	To analyze the just low carbon transition in authoritarian countries	China
[107]	Interviews	Need to consider justice in transition	To link energy justice, low carbon transition, and sustainable development	Vietnam
[108]	Comparative analyses	To link energy transitions, low-carbon transitions, and socio-technical change	To provide a general framework for the low-carbon energy transition	–
[109]	Comparative analyses	To study whether low-carbon energy transition could alleviate the energy poverty	To study the natural gas consumption impacts on China's energy poverty	China
[110]	semi-structured interviews	Need to reconstruct industries in the energy transition	To study the impact of industrial restructuring on the labor market	China
[111]	Interviews	need to consider social resistance and the government's role in the transition	To study a failed solar project to discover the social resistance's role.	China
[1]	Infrastructure-Based Optimization Approach	Need to find an affordable pathway to transition	to investigate transition costs with various low-carbon targets	China
[112]	Data Mining and Regression	Need to evaluate the public acceptance	To investigate public sentiment concerning solar energy	USA
[113]	Comparative analyses	Need to develop infrastructure in transition	To investigate the share of solar energy in Portugal	Portugal
[114]	Interviews	To understand the effect of direct investment on the energy transition	To study the direct and flow-on impacts of a direct-funding on low-carbon transition in shanghai	China
[115]	Stock-Flow Consistent model	The financial risk of energy transition	To understand the conditions under Green Supporting Factor (GSF) and global Carbon Tax (CT)	–
[116]	Retrospective analysis	Need to have specific strategies for transition	Ti studies the challenges to the energy transition	–
[117]	Content Analysis	Need to consider Energy security, equity, and sustainability	To investigate the energy transition doctrine in Russia	Russia
[118]	Content analysis	Need to analyze political conflicts surrounding low carbon energy transition and climate change.	To investigate the responses of crucial actors to climate-energy consultations concerning the EU emissions trading system (ETS) and renewable energy directive (RED)	EU
[119]	Survey and MCDA	Land scarcity is one of the main factors affecting REs	to identify methods that could contribute to mitigating land scarcity	the Netherlands, Belgium, Denmark, Germany, Latvia, and Sweden
[120]	Mathematical model	Need to study the impacts of the energy transition on the labor market	To forecast the loss of labor caused by the low-carbon energy transition	Poland
[121]	semi-structured interviews	To Study the role of law in the low-carbon energy transition	To study the energy transition law in Saudi Arabia from environmental and political perspectives	Saudi Arabia
[122]	Comparative analyses-MCDM	Need to consider justice and poverty in transition	To propose a framework to evaluate energy justice in transition	Lithuania and Greece

active engagement in a decentralized energy system [142]. Furthermore, solar and wind energy may encounter societal acceptability challenges [54,143,144]; however, energy planning might not begin with increasing public engagement and participation [99,145]. Also, public networks foster interaction and cross-sectoral cooperation among diverse organizations, improving decision-making and increasing public engagement [89,146].

Additionally, consumers' roles in the current energy system must be more reactive, adopting new low-carbon technologies by implementing them into daily lives [62]. [147] mentioned that acceptance by the community is a severe challenge associated with influencing political goals. Moreover, public support and social acceptance are significantly helpful in facilitating energy transition [92,148]. Also, Ryghaug et al. (2018) Mentioned that the energy transition requires significant public support, starting from public acceptance; however, public acceptance is far beyond simple acceptance or rejection. Also, it is believed that public support and acceptance of renewable energy may influence renewable energy policies, promoting renewable energy deployment [112]. Social acceptability issues will differ in socio-cultural settings. The low-carbon transition includes social shifts in all circumstances required to achieve an equitable transition [116].

Public education and awareness. Public education is critical for energy transition as it increases public awareness. The energy transition information must span spatial and temporal dimensions from small

Table 10
Studies published in 2022-23.

Author (s)	Methods	Research gap	Study aims	Case study location
[123]	Statistical methods	Economy concerns might impact the energy transition.	Investigating the impact of economic recovery after the Covid-19 pandemic on the low-carbon energy transition.	Worldwide
[124]	Multiple objective linear programs	Identifying how efficiently to mitigate greenhouse gas emissions and supply energy is required.	Identifying an optimal mix of various types of low-carbon energy transitions between developed and emerging countries	Worldwide
[125]	Mathematical models	Identifying the drivers of the low-carbon energy transition	Figure outing the incentives for choosing green or the low-carbon energy transition.	China
[126]	Transcendental logarithm production model	The role of technology must be considered more in adopting the low-carbon energy transition.	To estimate factor output and energy substitution among REs, oil, and gas.	North African countries
[127]	DEA	The impact of environmental regulations on renewable energy development must be analyzed.	To assess environmental regulations using a novel integrated method.	China
[128]	LEAP model, Case study	Climate change needs to promote a low-carbon energy transition.	Developing a comprehensive planning method.	China
[129]	DEMATEL	Offshore wind farms have faced many challenges needed to be analyzed.	Developing a multi-criteria method to examine challenges to adopting offshore farms.	India
[130]	System generalized method of moments	The low-carbon energy transition's social, economic, and environmental consequences must be analyzed.	Developing a novel comprehensive measure of common prosperity.	China
[131]	Synthetic control method	To figure out whether the low-carbon energy transition impedes air pollution.	Analyzing the impact of coal-to-gas policy on air pollution	China
[132]	Qualitative method	Environmental concerns must be considered in adopting the low-carbon energy transition.	Investigating the environmental policy dimensions of the low-carbon energy transition.	Brazil
[133]	Mathematical models	The low-carbon energy transition might reduce energy intensity.	Providing some policies for improving green innovation as it is caused intensity reduction	Worldwide
[134]	SEM	To measure public support for adopting the low-carbon energy transition	The willingness to pay of rural households is measured.	China
[135]	Qualitative method and literature review	To consider the change of business model innovation interactions with their wider environment.	Exploring the systems through which business activities interact with social policy aims.	–
[136]	Method of Moments Quantile Regression	ASEAN countries use more non-renewables, making the transition more difficult.	analyzing the impact of sustainable energy technologies, carbon finance, population growth, and carbon taxes on energy transition	ASEAN
[137]	Mathematical models	Covid-19 reduced the pace of energy transition.	To propose a road plan for moving toward a low-carbon system after Covid-19	China

geographic scales—individual companies and neighborhoods to cities and states [15,129]. Sharing helpful information and knowledge regarding low-carbon energy transition through public campaigns, energy-related websites, and standards is necessary [29]. Moreover, social movements can potentially boost policy development [149], demonstrating how emerging interests may raise public awareness and encourage decision-makers and companies to benefit from a low-carbon strategy [30]. [81] mentioned that a lack of awareness regarding the country's energy status is a barrier to the low-carbon energy transition reinforcing a need for public education. Also, a lack of shared awareness about energy security due to fossil fuel availability has resulted in sustainability [89]. [129] concluded that lack of awareness is an influential challenge to adopting offshore wind farms.

Moreover, It is noted that weak public awareness and inadequate training are barriers to adopting renewable energies [86,150]. Also, social learning is more feasible in societies with open, transparent, and participatory policymaking procedures and diverse professional and social networks [2]. Besides, there is a dichotomy between stakeholders' attitudes regarding decarbonization and the low-carbon energy transition, encouraging policymakers and leaders to increase awareness by improving public education [57]. Also, Siciliano et al. (2021) mentioned that improved education and training are needed for people impacted by low-carbon technologies. As a result, knowledge sharing and increasing awareness change behavior to achieve a low-carbon energy system [151].

Behavior change and resistance. Low-carbon technologies can enable the development of more responsive infrastructure to environmental and social imperatives; however, they also threaten critical revenue from affluent consumers that cross-subsidize electricity for low-income people [152]. In addition, widespread changes in consumers' energy usage are required to achieve a low-carbon energy future, and technical change is insufficient to achieve a low-carbon energy system. Behavior changes mean adopting low-carbon activities, such as less demand for household heating, reduced Vehicle Miles Traveled (VMT), and adopting low-carbon modes of transportation [29]. The magnitude of required change, the length of time, and the uncertainty associated with energy are critical feathers of the low-carbon energy transition, making low-carbon energy transition more difficult [15]. Nevertheless, the fundamental changes from the low-carbon energy transition need decades of policy development as social structures are gradually reconstructed in a low-carbon manner [153].

Furthermore, Technological innovations, appropriate policies, finance, and a systemic change in core behaviors, practices, and policies should be considered to have a low-carbon energy transition [59]. For example, transitioning from gasoline-powered to electric vehicles would require a shift in technology and customer preferences [154]. However, fossil fuels are necessary for human survival and economic prosperity. This distinction is commonly missed in the debate between proponents of the immediate need to alter human behavior and those seeking to preserve and sustain present socioeconomic arrangements [47]. Also, Holtz et al. (2018) confirmed that *Regime change* is needed for the low-carbon energy transition, which is done through consumer behavior, institutions, and infrastructure changes. On the other hand, *regime resistance* to developing low-carbon energy systems means that incumbent utilities might try to form a public debate around the negative impacts of low-carbon energy to halt or slow the low-carbon energy transition [111].

Energy justice. It could be defined as a worldwide energy system in which the advantages and disadvantages of energy services are distributed fairly among users [50,64]. Successful low-carbon transition requires a standard set of views, values, skills, interests, relationships, and resources grounded by knowing the need for sustainable routes [82, 155]. Failure to promote public engagement may result in less representative and responsive policy decisions, generating societal tension and hatred and increasing inequality and exclusion [79,156]. Moreover, there are four types of justice, including *procedural* [52]– participation in decision-making processes that promote equity; *distributional* [52]– the balance of environmental advantages and disadvantages; *recognition* [157,158]– the fair representation of persons who are not threatened physically and are guaranteed full equality political rights; *cosmopolitan*- All humans deserve just energy and are morally equal [159,160]. Furthermore, justice energy literature acknowledges “just energy transition,” which places social justice as central to energy transformations. Its goal is to avoid the upcoming phase of energy transitions from generating new social inequalities to exacerbating existing ones [1,122].

Decision-makers can directly consider energy justice while establishing new energy technologies. Increasing attention to procedural, distributive, and recognition of energy justice details might help "equalize" and "democratize" decarbonization measures [46,73,79]. [11] mentioned that energy justice is a niche for innovative discourses to advance alternative, participatory agendas and more democratic energy systems and decision-making. Stakeholders have clarified justice standards as *reconversion*: promoting industrial redevelopment in afflicted areas; *participation*: promoting greater engagement in the energy system; *compensation*: healing harm was done to individuals, society, investors, and nature; *distribution*: increasing the proximity of energy production to the point of consumption; *transparency*: presuming more clear decision-making procedures [37]; *plurality*: includes a diverse range of performers, perspectives, and decision-making situations [37].

Labor transition. The transition from coal could happen through a significant energy transition agreement signed by labor, unions, and governments to facilitate such a transition. It will boost coal mines' reformation and emphasize re-skilling employees to facilitate a just transition to adopt socioeconomic factors [11]. However, although the low-carbon energy transition may create several job openings in green industries, the overall effect on the labor force ultimately relies on the likelihood of people leaving the non-green sector to find work elsewhere. Optimistically, if all new green industry jobs were filled exclusively by workers who quit neutral industries, the transition's net inflationary effect would be a combination of job creation in green industries, job loss in neutral industries, and job loss in non-green industries [120]. Furthermore, there are constraints on dynamic labor markets since restrictions prohibit employees from transitioning from the current energy system to a low-carbon energy system due to skill shortages or mismatches, regional relocation challenges, and demographic issues [85]. Also, Bai et al. (2021) concluded that low carbon energy transition affects employment indirectly; therefore, labor transition needs more attention as perhaps the most significant societal consequence.

By renewing the structural workforce toward low-carbon industries, the impact on labor market regulations may help achieve the low-carbon transition. In this perspective, it is crucial to investigate whether REs technologies require more labor to deliver the same energy level as fossil fuels when jobs in associated activities such as equipment production, operation and maintenance (O&M), installation, and fuel supply are included [61]. [72] concluded that changes energy system would significantly impact labor demand across the economy. It is predicted that significant linkages would exist between employment growth and the requirement for various skill levels. Additionally, it is clear that companywide skill demands – both direct and indirect impacts the economy – can alter the labor market' need, which has consequences for labor market strategy in the low carbon transition. It should be noted that labor unions have worked to affect the allocation of advantages and disadvantages within energy systems by lobbying for and obtaining equitable distribution, recognition, and involvement primarily within current energy systems.

Energy security. A significant problem is ensuring countries move towards energy transitions considering energy equity and security [58]. Energy security is defined as the effectiveness of the primary energy mix from domestic and international sources and infrastructure dependability. Also, energy equity is defined as the affordability and accessibility of energy supply to all communities [161]. However, sustainability and affordability are already included in energy security, resilience, availability, and governance [162]. As a result [163], proposed four “Rs” to recognize and deduce what comes within energy security quickly, including *reviewing* available energy sources and suppliers, energy services and infrastructure, secure energy supplies and intensities; *reducing* energy demand through energy efficiency and conservation; *replacing* vulnerable energy supplies through altering infrastructure and diversification; *restricting* new demand to secured sources.

According to the four “Rs,” achieving energy security with sustainability and equity is challenging since it is needed to improve technologies, boost the local and global economy, and manage energy demand and supply [161]. [117] divided energy security into two categories: the security of supply and demand. Supply security ensures enough, dependable energy supply at reasonable rates and without jeopardizing critical national priorities and objectives. Demand security encompasses consumer availability, pricing fairness, and energy flow security.

3.2. Economic challenges

Economic challenges are presented in detail in the following, including incentives and investment risk, mitigation and adaptation costs, and subsidies.

Incentives and investment risk. There is a significant imbalance between the required funds to move toward low-carbon technologies and the available funds [164,165]; thus, increasing funds is required to fulfill climate change mitigation and adaptation requirements [60,64, 102]. However, disruptive innovations could reduce the cost of RE technology adoption but could increase the maintenance cost of the current energy grid [68,152]. Also, off-grid renewable technologies are relatively cost-effective for delivering advanced energy sources to rural households and may provide opportunities for improved development [9]; however, significant investment is required [28,51,103]. On top of that [62], concluded that developing REs technologies could temporarily decrease labor productivity and GDP; however, the duration and intensity depend on the investments required for REs technologies. Furthermore, more financial incentives are needed to motivate the civic energy sector in market-based economies [35]. Also, authorities should provide adequate incentives for low-carbon technologies to deal with the policy resistance and to represent a steadfast commitment to decarbonization [65].

Also, many challenges to low-carbon energy development remain without international cooperation and private investment [32,81]. However, non-profit investors or individuals do not have enough incentives to participate in renewable energy; even their engagement in renewable power is sometimes strongly discouraged [166]. For instance, solar panels' environmental tax owing to the incorporated carbon in the manufacturing system, the low feed-in tariffs, and the meager energy unit price established by the state are indirect or direct disincentives [76,89]. Also, governments should provide commercial incentives for investors to reduce investment risk since it is required for governments to demonstrate their contributions to low-carbon energy development when it comes to public money investment [37,84,115]. Furthermore, it is universally acknowledged that, first, the majority of these investment projects must be financed by private funds [8], and second, conservative mitigation initiatives must be implemented to achieve such a massive increase in private investment, which implies a consistent shift in private investment from current energy system to a low-carbon system [45,96].

Mitigation and adaptation costs. The term "mitigation costs" refers to the policy expenses associated with meeting climate goals. Thus, it is critical to define a realistic and cost-effective low-carbon energy transition to prevent the most severe effects of global warming [100,167,168]. Also, budget constraints and infrastructure privatization have adversely affected states' capacity to drive climate change mitigation and adaptation efforts [89]. Also, improving performance and cost reductions across technologies and their implementation in diverse contexts is complicated and widely covered in Technological innovation and socio-technical transition [147]. Furthermore [91], mentioned that the energy transition costs include operation, construction, various fuel types, maintenance, and the social cost of carbon emissions. Also, there is a critical need for new generations of biofuels to mitigate climate change; however, the higher cost of advanced biofuels may result in high mitigation costs for society [80].

The low-carbon transition will entail enormous energy system transition costs due to the complexity of energy systems characterized by novel technologies, carriers, spatial-temporal elements, and particularly high-investment infrastructure [93]. As a result, infrastructure investment is crucial because of large-scale renewable energy development. Also, phasing out fossil energy might result in system transition costs [55]. Therefore, Cost reduction is desirable but difficult since there is no one way to achieve a low-carbon energy system transition. Each way includes vast transition policies associated with different timing and speed, which would affect transition costs, despite all ways having the same goal [62].

Subsidies. Subsidies for fossil fuels have a significant environmental impact, stimulating renewables adoption, labor transition, and the low carbon transition [67]. Cutting down subsidies to minimize energy consumption and greenhouse gas emissions is needed. It is widely believed that fossil fuel subsidies encourage excessive energy use; eliminating them would reduce energy-related CO_2 emissions [95]. Also, Shem et al. (2019) mentioned that one of the impediments to renewable energy growth is the low price of coal and subsidies, which create an uncompetitive sector for more sustainable alternatives. However, it is possible to support the low-carbon energy transition through governmental support and subsidies; therefore, subsidies and tax credits effectively balance various enterprises' viability and market costs [92]. Furthermore, fossil-fuel costs are believed to be unpredictable and likely to continue rising, eventually making sustainable low-carbon energy more appealing. Thus, reducing subsidies would decrease the demand for fossil fuels, making low-carbon energy more feasible [28]. Additionally, the government must continue to reform the energy market and avert a resurgence of fossil fuel energy subsidies for energy products [83].

3.3. Environmental challenges

In the following, environmental challenges are presented in detail, including land acquisition, waste and pollution, and natural resource consumption.

Land acquisition. Land acquisition on a large scale is needed for the renewable energy transition, a distinguishing aspect of the current global land rush [16]. Ultra-mega solar parks require thousands of acres [169]. Despite these substantial financial investments, suitable lands are rare since they must have the appropriate size, be available, and be located in areas with solid energy demand [77]. Only government-controlled lands, such as 'wastelands' or 'marginal' lands, could meet the mentioned requirements. Land grabs are critical to the global land rush toward a low-carbon transition [170]. Land grabbing is a term that refers to the practice of enclosing enormous areas of land [171]. Moreover, “green grabbing” is another form of land grabbing in which land and natural resources are dispossessed under sustainable development [172]. Furthermore, for instance, solar PV power plant development has altered land-use patterns resulting in new land-use disputes [62]. Citizens may assert that the plant's visual effect breached their right to the landscapes, receive compensation for the inflationary pressure of property close to the site, and request that their land be reclassified under the plant's land [113].

Moreover, protecting high-biodiversity regions or places in danger of losing carbon pools may necessitate land-use restrictions, sometimes with economic compensation for landowners who forfeit revenue opportunities [42]. Also, it is predicted that the European Commission's plan for a low-carbon economy by 2050 emphasizes the importance of developing biofuels technologies to combat climate change, thereby bringing up other sustainability concerns associated with biofuels in general, such as biodiversity water management and land-use change [80,117]. [119] stated that land scarcity is a barrier to progress toward a low-carbon economy associated with the relatively high rising competition between land-use priorities, especially in the EU, such as the Netherlands.

Waste and pollution. The main challenge in waste and pollution management is nuclear energy waste—public concerns about radioactive waste [31]. Also, biofuels and biomass, considered alternatives to fossil fuels, could emit polluting substances, including carbon monoxide, through photosynthesis. On the other hand, the plants that provide biomass could collect the same quantity of CO2 produced by fossil fuels [42]. Also, there is a growing market for lithium-ion batteries (LIBs) for electric vehicles and auxiliary energy storage devices to support renewable sources. Recycling LIBs would not be a pollution-free activity. Also, pyrometallurgy is a high-energy process that generates GHG emissions and poisonous fumes or hazardous waste that must be landfilled [173]. However, one of the most severe risks linked with landfilling and unlawful processing is the formation of leachate: this substance is created due to numerous biological and chemical deterioration processes, as well as rain seeping through garbage [174].

Natural resource consumption. Mineral resource reliance is an illustrative example of the world's energy transition difficulties. Research has shown a shortage of diversity in raw material resources, such as copper, cobalt, and lithium.

[105] mentioned that global copper demand growth is projected to strain available copper production capacity further. In this respect, the

massive growth in copper usage should be accompanied by copper recycling. Also, it is believed that significant hazards arise primarily due to the growing importance of storage, which results in an increase in demand for natural resources, resulting in unavoidable environmental effects, such as mountainous areas for hydro storage and lithium extraction and sand for construction [97,98]. Also, dangers would arise due to incorporating carbon capture and storage (CCS), and the influence of climate change may have an effect on the availability of renewable energy [80]. In addition, long-term but low-cost supplies are crucial for implementing biomass power plants, and insufficient biomass resources constitute a barrier to low-carbon energy adoption [95].

3.4. Institutional challenges

In the following, institutional challenges are presented in detail, including short-termism, anti-innovation, and conflicts and reformations.

Short-termism. One of the barriers to low-carbon energy development is short-term policies ratified by governments to survive politically and economically [43,49]. For example, in petrostates like Iran, Kuwait, and Iraq with high budgetary break-even points (BEP), ensuring short-term revenue is critical for political positions [175]. Moreover [89], mentioned that short-termism is a public policy formulation and execution, restricting the alternatives for integrating short-term decisions with long-term goals. In addition, government engagement in the energy transition is most likely to address the long-term external cost of energy usage rather than delivering a short-term private advantage [2].

Therefore, decision-makers must struggle with technical uncertainty and short timelines incompatible with long-term system transformation. In contrast, it progresses beyond incremental interventions to substantial structural change within socio-political restrictions [147,176]. Furthermore, cooperation between governments and parties will be critical to establishing a path to a low-carbon energy transition; thus, long-term collaboration and partnership provide significant prospects for accelerating technological and system innovation, scaling up collaboration, and increasing financial availability [92,177].

Anti-innovation policies. Innovative policies are required to support the low-carbon energy transition to reconfigure the current status of energy sectors [40]. Also, Chen and Kim (2019) mentioned that anti-innovation policies could hamper innovations, similar to public resistance and investment risks [104]. mentioned that appropriate renewable energy policies under international support must be applied to mining, transport, and industry sectors to decrease emissions dramatically on the demand side. In addition, although carbon pricing is usually regarded as the fundamental of sustainable climate mitigation policies, there is also a necessity for innovative policies, such as subsidies, regulations, and information supply, to boost innovation and eliminate barriers to low-carbon paths [15]. Also, policies must incorporate measures that promote renewable energy technologies to facilitate the transition to a low-carbon economy [81]. In other words, the government actions should be sustained over time, so all policies should always be coordinated to meet low-carbon energy transition targets [55, 111,116,178] also confirmed that the central government entities play a critical role for solar PV in China, and Bracco (2020) confirmed that new policies are needed to support electricity storage systems (ESS) in the North of Italy. Also, Werner and Lazaro (2023) concluded that implementing climate and sustainable energy policies needs political will and public support.

Conflicts and reformations. Transition governance is a multi-faceted, multi-actor, multi-level, and multi-phase governing process that enables systemic transitions of socio-technical systems toward sustainability [118]. Therefore, gradual reformation is needed, especially in authoritarian countries, which generally maintain rules, causing conflicts in transiting to low-carbon energy systems [90]. Constant conflicts may be observed throughout the various stages of policy development, such as the political conflict in determining tariffs, which directly affect investment returns [63]. Typically, states play a significant role in transition governance, widely described in its democratic form as the triangle of executive, legislative, and judiciary authority [88]. The state's tasks in the transition governance process include regulating, coordinating, providing, introducing, managing, and safeguarding [179]. The constraints on preserving policy credibility are underscored by explicitly outlining the degree of flexibility with which regulations can be (re)designed [180], particularly when such changes contradict institutionalized forecasts of future policy changes in key aspects of the policy mix [65]. On top of that, public awareness, the macro economy, and policy channels may be mutually reinforcing since policy reforms may raise public awareness, influencing consumer decisions [30].

3.5. Technical challenges

In the following, institutional challenges are presented in detail, including a lack of technical standards and infrastructure.

Lack of technical standards. The low-carbon energy transition will need the widespread adoption of novel technologies, regulations, and policies, such as carbon pricing regimes and regulatory standards [15], or sometimes even fewer regulations concerning renewable energy development [81]. A comprehensive set of standards and regulations pushes the energy supply to follow a predetermined path [92]. Also, Gössling and Scott (2018) mentioned that many stakeholders had confirmed a lack of standards hindering the low-carbon energy transition, and [117] concluded that the required regulatory frameworks are underdeveloped, impeding the implementation of novel technologies in the energy industry, including distributed electric energy, renewable energy, and information technology. In addition, Failure to include all potential influencing operations and toxic pollutants in decision-making and legislation enables legal waste production [98]. Also, while environmental guidelines are focused on gaseous emissions, it is theoretically conceivable for enterprises to change their processes to release toxins in plenty of other sources, such as the air or groundwater [121].

Lack of infrastructure. System transition requires a fundamental change in infrastructures, politics, and customer behavior [44,154]. For example, transitioning from gasoline-powered automobiles to electric vehicles would involve a shift in automotive innovation and technology and an entirely new infrastructure equipped with electric charging points [59]. Changing demand for renewable energy threatens the grid's stability and flexibility because an innovative energy infrastructure seems to be a precondition for the energy transition, which entails several implementation risks [98]. On top of that [89], concluded that the privatization of infrastructure had reduced the capacity of states to manage climate change mitigation and adaptation efforts; however, short-term emissions reduction requires technical changes [71], including new infrastructure; and social changes, such as overcoming fragmentation to provide new infrastructure. Also, Kuamoah (2020), another impediment to renewable energy penetration is a lack of infrastructure, notably aging and undeveloped national grid networks; however, decisions regarding which resources to focus on and where to develop new infrastructure may result in unequal regional economic development and energy poverty at the local and household level [36, 39]. Renewables need energy storage alternatives to match energy demand reliably at various time scales [181].

As mentioned, seventeen challenges to the low-carbon energy transition have been identified in the present research, illustrated in Fig. 4.

4. Conclusions

The low-carbon energy transition is a socio-technical transition requiring decision-makers and researchers to deal with many social, economic, environmental, technical, and institutional challenges. To this end, decision-makers and researchers should know the challenges and how they should be tackled to accurately follow the timelines

Fig. 4. The framework of challenges to the low carbon energy transition.

presented in global agreements, such as the Paris agreement. Therefore, the present study conducted a systematic literature review using an integrated methodology to review 123 publications out of over 1000 found articles on the low-carbon energy transition to propose a comprehensive framework addressing social challenges, such as public acceptance and engagement, public education and awareness, behavior change and resistance, energy justice, labor transition, and energy security; economic challenges, such as incentives and investment risk, mitigation and transition costs, and subsidies; environmental challenges, such as land acquisition, waste and pollution, and natural resources consumption; and institutional challenges, such as short-termism, anti-innovation policies, conflicts and reformations; technical challenges, such as lack of technical standards, and lack of infrastructure. On top of that, many researchers have applied various qualitative and quantitative methods over the years, motivating the present study to provide information regarding applied methodologies, case study locations, and obtained results.

Furthermore, the publication rate on the low-carbon energy transition has grown dramatically since 2016; thus, it could be concluded that the Paris agreement, one of the most influential agreements in climate change mitigation, has significantly motivated researchers to study the low-carbon energy transition increasingly. Also, it could be concluded that transiting towards low-carbon energy systems is a complex and inter-connected process in which scientific, political, social, etc. interactions; thus, all influential factors should be considered in developing policies, agendas, or even conducting research; otherwise, the results would not be effective enough to reach the climate change mitigation's goals. Results indicated that technologies that enable enhanced or new services are critical in catalyzing a transformation, even if they are initially prohibitively expensive. Governments are frequently absent during such changes. The government's engagement in the energy transition is most likely, as it is costly and motivated by the necessity to address the long-term external cost of energy usage to the public rather than delivering a short-term private advantage. Markets alone will not affect the necessary behavioral changes in the timeframe required. The apparent lack of time left for the worldwide low-carbon transition also separates it from previous regime changes and makes this transition particularly difficult. As a result, governments must devote themselves to transforming technologies and behaviors to improve energy production technology because history demonstrates that improvements in end-use technologies drive most energy transitions. Nevertheless, changing end-user behavior to achieve the benefits of technology innovation needs a significant institutional transition in most societies.

4.1. Research agenda

Furthermore, many research gaps in the low-carbon energy transition should be studied according to the future directions provided by researchers over the years. The present study classified them into *replication* studies and *new avenue* studies. The new case studies group devotes to those studies in which a new framework or analyzing model was applied to case studies; then, they also recommended that to reapply their study to another case study. The replication studies are presented in the following.

- Recommendations for applying multicriteria decision analysis models under fuzzy sets:
  - o Nikas et al. (2018) recommended applying the integrated FCM-DSGE-BSAM method to the energy mix and pricing strategy affecting energy security; however, FCM could deal with both quantitative and qualitative problems; thus, it is possible to include social, environmental, institutional, and technical factors to cognitive maps to make a comprehensive model of the current status of the low-carbo energy transition; also possible to run the model under various scenario to see the results under various assumptions.
  - o Shem et al. (2019) recommended applying the MCDM method to evaluate the policies' efficiency by stakeholders; however, the MCDM method could include a variety of factors related to all identified challenges, not only institutional or pollical. Also, MCDM methods usually are integrated with fuzzy logic to improve their accuracy and applicability under various assumptions to deal with vagueness and uncertainty in MCDM problems.
  - o Janssen et al. (2020) recommended integrating system modeling with MCDM in dealing with land scarcity issues. Location selections are multi-criteria problems in which MCDM could identify the best location to build solar or wind farms; however, the present study recommends integrating MCDM methods with ArcGIS to improve the obtained results from location selection.
  - o Bracco (2020) recommended finding the optimal location of the storage systems and new renewable power plants. Finding the best location could deal with land scarcity, and the present study recommends integrating MCDM and mapping methods to deal with location selection problems.
- Recommendations for applying assessment models:
  - o Pizarro-Irizar et al. (2020) recommended applying the GCAM model in future studies to study more on GDP and cost impacts caused by climate change. However, adding economic factors to the GCAM model makes future studies novel; it is also possible to add technical and institutional factors to this model to make the obtained results more accurate.
  - o [104] recommended applying the LEAP model in various countries or regions, not just Chile. As mentioned above, applying a model to other countries could make future studies; however, integrating the LEAP model with linear programming is recommended, such as [86] study.
  - o [80] recommended applying to apply Life-Cycle Assessment (LCA) to assess potential environmental effects stemming from the development of next-generation biofuel; however, the present study recommends integrating LCA with other assessment frameworks, such as techno-economic analysis (TEA) and life-cycle costing (LCC) to boost the accuracy and inclusiveness of the future studies.
- o Chilvers and Longhurst (2016) suggested applying their proposed framework under other collective engagement in system change, not just public participation in the energy transition; however, the present study recommends applying the [34] framework to other social challenges identified in this study, making future studies more comprehensive in which most of the social challenges are addressed.
- o Alomari and Heffron (2021) recommended repeating their research in the middle east context, not only in Saudi Arabia; however, the present study recommends applying quantitative methods to analyze collected data, not just descriptive statistics.
- Recommendations for applying mathematical and probabilistic models:
- o [33] recommended applying the proposed linear programming to the rest of Latin America, not just Nicaragua; thus, changing case studies' locations could add novelty to future research, and also, it is possible to compare the results of the future studies with [33] study to figure out how the proposed method works under different conditions and assumptions.
- o Rogge and Dütschke (2018) recommended applying the proposed linear regression model to deal with the issues in other countries, not just Germany, and applying more complex models to capture interdependencies between elements. Linear regression has many extensions, such as marginal models, GEE models, generalized linear models, generalized linear mixed models, and linear mixed models; thus, applying other extensions of linear regression is also recommended. Furthermore, Artificial Neural Networks (ANN) could be an alternative method to regression analysis, making future studies more accurate and novel.
- o Chen et al. (2018) recommended improving the integrated agent-based model by including uncertainties; however, the present study recommends including all identified challenges to the agent-based model to make the model comprehensive.
- o Streimikiene et al. (2021) recommended applying fuzzy Monte Carlo to address uncertainties. As mentioned, fuzzy logic could deal with uncertainties; the present study recommends integrating novel fuzzy extensions with Mont Carlo, such as Fermatean fuzzy sets, making future studies novel.
- o Bachner et al. (2020) recommended applying micro-scale and agent-based models to address investment risks in transiting to low-carbon energy; however, as mentioned, other challenges should be included in the assessment and evaluation models to improve the accuracy and reliability of the obtained results.

Furthermore, some researchers have recommended *new avenues* for future research in the low-carbon energy transition. These studies thoroughly recommend a new research idea, not recommending reapplying a method to other case studies or repeating a study in different locations. New avenue studies are presented in the following.

- Recommendations for more studies on social challenges:
  - o Stock and Birkenholtz (2019) recommended more debates on agrarian labor contributions in solar parks. Labor market transition is one of the social challenges; however, the present study recommends considering all identified social challenges in future studies.
  - o Axsen and Kurani (2012) recommended studying the effect of interpersonal influence on adopting low-carbon products. Public engagement affects the pace of the low-carbon energy transition; however, other social challenges, especially public awareness, should be considered as their interaction affects future studies' results.
  - o Bellos (2018) recommended studying public engagement for innovation and marine energy. All recommendations of [53] align with the results of the present study as the proposed framework included all these factors and more; thus, the present study recommends considering the proposed framework of challenges in future studies.
  - o Zeyringer et al. (2018) recommended studying the impacts of marine energy on job creation, regional development, and new export opportunities. Marine energy is non-carbon energy and affects the labor market; thus, the present study recommends studying the impacts of marine energy on energy security and energy poverty, as these social challenges affect regional development and export opportunities.
  - o Hu (2020) recommended studying how households could adopt new low-carbon technologies in rural areas. Adopting new low-carbon technologies in rural areas could affect energy poverty; thus, the transition could be more successful; however, technology adoption requires increased public engagement and awareness; thus, innovative policies might be developed to overcome the challenges of new low-carbon technology adoption.

- Recommendations for more studies on economic challenges:
  - o Chen and Kim (2019) recommended empirical studies concerning energy transition and circular economy collaboration. The circular economy is a novel following seven principles, including rethink, reuse, recycle, reduce, refurbish, repair, and recover. These seven principles could boost the low-carbon energy transition, especially in waste management.
  - o Hoggett (2014) recommended studying supply chains and low-carbon technologies. Studying low-carbon supply chains could be a novel topic for future research, and the present study recommends studying the circular supply chains in which seven principles of circular economy enable supply chains to be low-carbon.
  - o Hall et al. (2016) recommended investigating how bank-based vs. market-based economies affect the links between capitalism and energy policies. Studying low-carbon energy transition from various perspectives improves the understanding of the current status of the low-carbon energy transition; however, not from only economic perspectives.
  - o Malakar et al. (2019) recommended studying the responsibilities of developing countries toward a low-carbon energy transition compared to advanced economies worldwide. The present study recommends evaluating the performance of advanced counties in dealing with the challenges of the low-carbon energy transition; consequently, other countries could follow those countries to improve their energy systems to reach low-carbon goals.
  - o Schinko and Komendantova (2016) recommended studying the perceived risks' impacts on investing in the low-carbon energy transition. Investment risks are a critical economic challenge to the low-carbon energy transition, affecting the pace of the transition. The present study recommends investigating the relationship between public engagement and perceived risks and their effects on investment.
- Recommendations for more studies on environmental challenges:
  - o Seck et al. (2020) recommended studying water resource availability impacts on raw material demand and the energy transition. Raw materials consumption is a severe challenge to the low-carbon energy transition; thus, the present study recommends studying the role of the circular economy in reducing the required raw materials for transiting to a low-carbon energy system.
- Recommendations for more studies on institutional challenges:
  - o Muinzer and Ellis (2017) recommended more political analyses to elucidate energy transitions; however, the present study recommends including all institutional factors affecting the low-carbon energy transition, not only political analyses. Also, as challenges are interconnected, analyzing the low-carbon energy transition as a whole is recommended to see the factors' interactions and their impact on the obtained results.
  - o Urban and Nordensvärd (2018) recommended studying historical energy transitions in Nordic countries. Studying the background of energy transition might provide some new ideas or solutions to the challenges of the low-carbon energy transition; however, more practical studies in which a specific challenge would be studied are also recommended.
  - o Hall et al. (2018) recommended investigating how future energy policies boost energy justice; However, energy justice is critical to transiting toward a low-carbon energy system. Other significant social challenges, especially energy security, should be considered in policy-making.
  - o Power et al. (2016) recommended developing the conceptual framework considering the relationship between socio-technical transitions and political economy. However, political and economic issues are not the only challenges that need to be considered in studying the low-carbon energy transition; thus, the conceptual framework should include all challenges to the low-carbon energy transition.
  - o [84] studied the political challenges of building retrofitting. Although adopting new low-carbon technologies to the old building might face political issues, retrofitting might pose many social challenges as it directly affects people.
  - o Monasterolo and Raberto (2019) recommended policy-relevant studies on phasing out fossil fuel subsidies. Studying subsidies' contribution to the low-carbon energy transition could be interesting for future research; however, studying the impacts of only one challenge might affect the obtained results, as many other challenges are connected to subsidies and policy-relevant studies.
  - o Huang (2021) recommended doing comprehensive research regarding the governance of urban energy transitions. Studying the low-carbon energy transition in urban and rural areas could identify the specific challenges to low-carbon technologies adoption in these areas. However, the present study recommends measuring the performance of countries in dealing with identified challenges in rural and urban areas to figure out the most critical challenges in these areas in a country.
- Recommendations for more studies on technical challenges:
  - o Baker and Phillips (2019) recommended studying the rapid evolution of disruptive technologies changing electricity governance structures. Disruptive innovation could change the pace and the path of the low-carbon energy transition; however, disruptive innovation requires developing many policies to support innovative technologies.

4.2. Policy recommendations

- How individuals and organizations perceive uncertainties and risks could affect climate policy design. Valuation methods from the social, environmental, economic, technical, and institutional analysis could assist decision-making under uncertainties. Also, mitigation and adaptation could reduce perceived risks, as are complementary strategies.
- Substantial GHG emissions reductions over the next decades could reduce climate risks, costs, and challenges to the low(non)-carbon energy transition in the longer term, building pathways to sustainable development. However, significant changes in investment patterns are required for substantial reductions, and both public and private sectors could have an essential role in financing the low-carbon energy transition.
- There are substantial interactive effects across different energy policy goals, such as just energy, energy security, energy access, and energy availability, and between other technical, social, institutional, and environmental goals. Cost-effectiveness, multi-criteria, and cost-benefit analysis could assist integrated methods for energy policy developments.
- Public education is a social challenge increasing public engagement and reducing public resistance to change. Thus, supportive and clear policies should be developed, especially in the transportation system, considered a carbon emissions resource. For instance, all sectors should provoke employees to utilize low-carbon modes of transportation, such as electric vehicles (EVs), and provide EV charging stations for visitors and employees. Also, a government-verified transportation program should be developed to address carbon emissions reduction.
- Economic instruments like subsidies could be employed across various sectors, including different policy designs, such as tax exemptions, rebates, loans, grants, and credit lines. On the other hand, decreasing subsidies for GHG-related sectors could result in emission reductions, depending on the economic and social context. However, sector-specific policies might work better than economy-wide policies as they could address sector-specific challenges.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

References

[1] P. Huang, Y. Liu, Toward just energy transitions in authoritarian regimes: indirect participation and adaptive governance, © 64 (2021) 1–21.
[2] P. Andrews-Speed, Applying institutional theory to the low-carbon energy transition, Energy Res. Social Sci. 13 (2016) 216–225.
[3] A. Farsaei, V. Olkkonen, X. Kan, S. Syri, Electricity market impacts of low-carbon energy transition in the nordic-baltic region, Journal of Sustainable Development of Energy, Water and Environment Systems 10 (2022) 1–23.
[4] S. Laakso, E. Heiskanen, K. Matschoss, E.-L. Apajalahti, F. Fahy, The role of practice-based interventions in energy transitions: a framework for identifying types of work to scale up alternative practices, Energy Res. Social Sci. 72 (2021), 101861.
[5] J.T. Nuru, J.L. Rhoades, B.K. Sovacool, Virtue or vice? Solar micro-grids and the dualistic nature of low-carbon energy transitions in rural Ghana, Energy Res. Social Sci. 83 (2022), 102352.
[6] Ş. KıLKıŞ, G. Krajačić, N. Duić, M.A. Rosen, Effective Mitigation of Climate Change with Sustainable Development of Energy, Water and Environment Systems, Elsevier, 2022.
[7] D. Meha, A. Pfeifer, N. Sahiti, D.R. Schneider, N. Duić, Sustainable transition pathways with high penetration of variable renewable energy in the coal-based energy systems, Appl. Energy 304 (2021), 117865.
[8] C. Kuamoah, Renewable energy deployment in Ghana: the hype, hope and reality, Insight Afr. 12 (2020) 45–64.
[9] M.K. Saraji, E. Aliasgari, D. Streimikiene, Assessment of the challenges to renewable energy technologies adoption in rural areas: a Fermatean CRITIC-VIKOR approach, Technical Forecasting and Social Change 189 (2023), 122399.
[10] I.C. Change, Mitigation of climate change, in: Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 2014, p. 1454.
[11] A.H. Sorman, X. García-Muros, C. Pizarro-Irizar, M. González-Eguino, Lost (and found) in transition: expert stakeholder insights on low-carbon energy transitions in Spain, Energy Res. Social Sci. 64 (2020), 101414.
[12] M. Kamali Saraji, D. Streimikiene, R. Ciegis, A novel Pythagorean fuzzy-SWARA-TOPSIS framework for evaluating the EU progress towards sustainable energy development, Environ. Monit. Assess. 194 (2022) 42.
[13] D. Boulogiorgou, P. Ktenidis, TILOS local scale Technology Innovation enabling low carbon energy transition, Renew. Energy 146 (2020) 397–403.
[14] P. Johnstone, K.S. Rogge, P. Kivimaa, C.F. Fratini, E. Primmer, A. Stirling, Waves of disruption in clean energy transitions: sociotechnical dimensions of system disruption in Germany and the United Kingdom, Energy Res. Social Sci. 59 (2020), 101287.
[15] D. Rosenbloom, J. Meadowcroft, S. Sheppard, S. Burch, S. Williams, Transition experiments: opening up low-carbon transition pathways for Canada through innovation and learning, Can. Publ. Pol. 44 (2018) 368–383.
[16] S. Avila, Environmental justice and the expanding geography of wind power conflicts, Sustain. Sci. 13 (2018) 599–616.
[17] K. Johansen, H. Johra, A niche technique overlooked in the Danish district heating sector? Exploring socio-technical perspectives of short-term thermal energy storage for building energy flexibility, Energy 256 (2022), 124075.
[18] M.J. Grant, A. Booth, A typology of reviews: an analysis of 14 review types and associated methodologies, Health Inf. Libr. J. 26 (2009) 91–108.
[19] M.A. Saldías Fernández, C. Luengo Martínez, Influence of nursing in health economics: an integrative review of literature, Salud Uninorte 38 (2022).
[20] I. Siksnelyte-Butkiene, D. Streimikiene, V. Lekavicius, T. Balezentis, Energy poverty indicators: a systematic literature review and comprehensive analysis of integrity, Sustain. Cities Soc. 67 (2021), 102756.
[21] J. Streimikis, M.K. Saraji, Green productivity and undesirable outputs in agriculture: a systematic review of DEA approach and policy recommendations, Economic Research-Ekonomska Istraživanja 35 (2022) 819–853.
[22] D. Moher, L. Stewart, P. Shekelle, Implementing PRISMA-P: recommendations for prospective authors, Syst. Rev. 5 (2016) 1–2.
[23] A. Mardani, D. Streimikiene, F. Cavallaro, N. Loganathan, M. Khoshnoudi, Carbon dioxide (CO2) emissions and economic growth: a systematic review of two decades of research from 1995 to 2017, Sci. Total Environ. 649 (2019) 31–49.
[24] P.C. Murschetz, A. Omidi, J.J. Oliver, M.K. Saraji, S. Javed, Dynamic capabilities in media management research: a literature review, J. Strat. Manag. 13 (2) (2020) 278–296.
[25] M.K. Saraji, A.M. Sharifabadi, Application of system dynamics in forecasting: a systematic review, Int. J. Manag. Account. Econ. 4 (2017) 1192–1205.
[26] W. Mengist, T. Soromessa, G. Legese, Method for conducting systematic literature review and meta-analysis for environmental science research, MethodsX 7 (2020), 100777.
[27] A. Booth, A. Sutton, M. Clowes, M. Martyn-St James, Systematic Approaches to a Successful Literature Review, 2021.
[28] F. Urban, Climate-Change Mitigation Revisited: low-carbon energy transitions for China and India, Dev. Pol. Rev. 27 (2009) 693–715.
[29] J. Axsen, K.S. Kurani, Social influence, consumer behavior, and low-carbon energy transitions, Annu. Rev. Environ. Resour. 37 (2012) 311–340.
[30] T. Wakiyama, E. Zusman, J.E. Monogan III, Can a low-carbon-energy transition be sustained in post-Fukushima Japan? Assessing the varying impacts of exogenous shocks, Energy Pol. 73 (2014) 654–666.
[31] R. Hoggett, Technology scale and supply chains in a secure, affordable and low carbon energy transition, Appl. Energy 123 (2014) 296–306.
[32] R. Bolton, T.J. Foxon, Infrastructure transformation as a socio-technical process—implications for the governance of energy distribution networks in the UK, Technical Forecasting and Social Change 90 (2015) 538–550.
[33] D.P. DE Leon Barido, J. Johnston, M.V. Moncada, D. Callaway, D.M. Kammen, Evidence and future scenarios of a low-carbon energy transition in Central America: a case study in Nicaragua, Environ. Res. Lett. 10 (2015), 104002.
[34] J. Chilvers, N. Longhurst, Participation in transition (s): reconceiving public engagements in energy transitions as co-produced, emergent and diverse, J. Environ. Pol. Plann. 18 (2016) 585–607.
[35] S. Hall, T.J. Foxon, R. Bolton, Financing the civic energy sector: how financial institutions affect ownership models in Germany and the United Kingdom, Energy Res. Social Sci. 12 (2016) 5–15.
[36] M. Power, P. Newell, L. Baker, H. Bulkeley, J. Kirshner, A. Smith, The political economy of energy transitions in Mozambique and South Africa: the role of the Rising Powers, Energy Res. Social Sci. 17 (2016) 10–19.
[37] P. Newell, J. Phillips, Neoliberal energy transitions in the South: Kenyan experiences, Geoforum 74 (2016) 39–48.
[38] Q. Liu, Y. Chen, C. Tian, X.-Q. Zheng, J.-F. Li, Strategic deliberation on development of low-carbon energy system in China, Adv. Clim. Change Res. 7 (2016) 26–34.
[39] S. Ćetković, A. Buzogány, Varieties of capitalism and clean energy transitions in the European Union: when renewable energy hits different economic logics, Clim. Pol. 16 (2016) 642–657.
[40] H. Haarstad, Where are urban energy transitions governed? Conceptualizing the complex governance arrangements for low-carbon mobility in Europe, Cities 54 (2016) 4–10.
[41] T. Schinko, N. Komendantova, De-risking investment into concentrated solar power in North Africa: impacts on the costs of electricity generation, Renew. Energy 92 (2016) 262–272.
[42] R. Hildingsson, B. Johansson, Governing low-carbon energy transitions in sustainable ways: potential synergies and conflicts between climate and environmental policy objectives, Energy Pol. 88 (2016) 245–252.
[43] K.S. Rogge, P. Johnstone, Exploring the role of phase-out policies for low-carbon energy transitions: the case of the German Energiewende, Energy Res. Social Sci. 33 (2017) 128–137.
[44] T.L. Muinzer, G. Ellis, Subnational governance for the low carbon energy transition: mapping the UK's 'Energy Constitution, Environ. Plan. C Politics Space 35 (2017) 1176–1197.
[45] S. Hall, T.J. Foxon, R. Bolton, Investing in low-carbon transitions: energy finance as an adaptive market, Clim. Pol. 17 (2017) 280–298.
[46] N. Healy, J. Barry, Politicizing energy justice and energy system transitions: fossil fuel divestment and a "just transition", Energy Pol. 108 (2017) 451–459.
[47] P.S. Ringrose, Principles of sustainability and physics as a basis for the low-carbon energy transition, Petrol. Geosci. 23 (2017) 287–297.
[48] B.K. Sovacool, Contestation, contingency, and justice in the Nordic low-carbon energy transition, Energy Pol. 102 (2017) 569–582.
[49] M. Åhman, L.J. Nilsson, B. Johansson, Global climate policy and deep decarbonization of energy-intensive industries, Clim. Pol. 17 (2017) 634–649.
[50] E. Schmid, A. Pechan, M. Mehnert, K. Eisenack, Imagine all these futures: on heterogeneous preferences and mental models in the German energy transition, Energy Res. Social Sci. 27 (2017) 45–56.
[51] H.J.J. Yu, Virtuous cycle of solar photovoltaic development in new regions, Renew. Sustain. Energy Rev. 78 (2017) 1357–1366.
[52] L. Mundaca, H. Busch, S. Schwer, 'Successful'low-carbon energy transitions at the community level? An energy justice perspective, Appl. Energy 218 (2018) 292–303.
[53] E. Bellos, Sustainable energy development: how can the tension between energy security and energy transition be measured and managed in South Africa? J. Clean. Prod. 205 (2018) 738–753.
[54] S. Pilpola, P.D. Lund, Effect of major policy disruptions in energy system transition: case Finland, Energy Pol. 116 (2018) 323–336.
[55] F. Urban, Y. Wang, S. Geall, Prospects, politics, and practices of solar energy innovation in China, J. Environ. Dev. 27 (2018) 74–98.
[56] M. Ryghaug, T.M. Skjølsvold, S. Heidenreich, Creating energy citizenship through material participation, Soc. Stud. Sci. 48 (2018) 283–303.
[57] S. Gössling, D. Scott, The decarbonisation impasse: global tourism leaders' views on climate change mitigation, J. Sustain. Tourism 26 (2018) 2071–2086.
[58] S. Sareen, S.S. Kale, Solar 'power': socio-political dynamics of infrastructural development in two Western Indian states, Energy Res. Social Sci. 41 (2018) 270–278.
[59] F. Urban, J. Nordensvärd, Low carbon energy transitions in the Nordic countries: evidence from the environmental Kuznets curve, Energies 11 (2018) 2209.

[60] M. Zeyringer, B. Fais, I. Keppo, J. Price, The potential of marine energy technologies in the UK–Evaluation from a systems perspective, Renew. Energy 115 (2018) 1281–1293.
[61] P. Fragkos, L. Paroussos, Employment creation in EU related to renewables expansion, Appl. Energy 230 (2018) 935–945.
[62] A. Nikas, V. Stavrakas, A. Arsenopoulos, H. Doukas, M. Antosiewicz, J. Witajewski-Baltvilks, A. Flamos, Barriers to and consequences of a solar-based energy transition in Greece, Environ. Innov. Soc. 35 (2018) 383–399.
[63] W. Shen, L. Xie, The political economy for low-carbon energy transition in China: towards a new policy paradigm? New Polit. Econ. 23 (2018) 407–421.
[64] S. Hall, K.E. Roelich, M.E. Davis, L. Holstenkamp, Finance and justice in low-carbon energy transitions, Appl. Energy 222 (2018) 772–780.
[65] K.S. Rogge, E. Dütschke, What makes them believe in the low-carbon energy transition? Exploring corporate perceptions of the credibility of climate policy mixes, Environ. Sci. Pol. 87 (2018) 74–84.
[66] G. Holtz, C. Xia-Bauer, M. Roelfes, R. Schüle, D. Vallentin, L. Martens, Competences of local and regional urban governance actors to support low-carbon transitions: development of a framework and its application to a case-study, J. Clean. Prod. 177 (2018) 846–856.
[67] J. Li, C. Sun, Towards a low carbon economy by removing fossil fuel subsidies? China Econ. Rev. 50 (2018) 17–33.
[68] H. Chen, C. Wang, W. Cai, J. Wang, Simulating the impact of investment preference on low-carbon transition in power sector, Appl. Energy 217 (2018) 440–455.
[69] W. Shen, J. Qiu, Z. Dong, Electricity network planning targeting Low-Carbon energy transition, Global Energy Interconnection 1 (2018) 487–499.
[70] M. Mcpherson, N. Johnson, M. Strubegger, The role of electricity storage and hydrogen technologies in enabling global low-carbon energy transitions, Appl. Energy 216 (2018) 649–661.
[71] B. Guler, E. Çelebi, J. Nathwani, A 'Regional Energy Hub'for achieving a low-carbon energy transition, Energy Pol. 113 (2018) 376–385.
[72] G.J. Allan, A.G. Ross, The characteristics of energy employment in a system-wide context, Energy Econ. 81 (2019) 238–258.
[73] B.K. Sovacool, A. Hook, M. Martiskainen, L. Baker, The whole systems energy injustice of four European low-carbon transitions, Global Environ. Change 58 (2019), 101958.
[74] M. Zhang, Q. Wang, D. Zhou, H. Ding, Evaluating uncertain investment decisions in low-carbon transition toward renewable energy, Appl. Energy 240 (2019) 1049–1060.
[75] B. Lin, M. Xu, Good subsidies or bad subsidies? Evidence from low-carbon transition in China's metallurgical industry, Energy Econ. 83 (2019) 52–60.
[76] B.-J. Tang, R. Li, B. Yu, Y.-M. Wei, Spatial and temporal uncertainty in the Technical pathway towards a low-carbon power industry: a case study of China, J. Clean. Prod. 230 (2019) 720–733.
[77] R. Stock, T. Birkenholtz, The sun and the scythe: energy dispossessions and the agrarian question of labor in solar parks, J. Peasant Stud. (2019) 1–24.
[78] A. Golub, O. Lugovoy, V. Potashnikov, Quantifying barriers to decarbonization of the Russian economy: real options analysis of investment risks in low-carbon technologies, Clim. Pol. 19 (2019) 716–724.
[79] B.K. Sovacool, M. Martiskainen, A. Hook, L. Baker, Decarbonization and its discontents: a critical energy justice perspective on four low-carbon transitions, Climatic Change 155 (2019) 581–619.
[80] K. Vaillancourt, O. Bahn, A. Levasseur, The role of bioenergy in low-carbon energy transition scenarios: a case study for Quebec (Canada), Renew. Sustain. Energy Rev. 102 (2019) 24–34.
[81] C. Shem, Y. Simsek, U.F. Hutfilter, T. Urmee, Potentials and opportunities for low carbon energy transition in Vietnam: a policy analysis, Energy Pol. 134 (2019), 110818.
[82] Y. Malakar, M.J. Herington, V. Sharma, The temporalities of energy justice: examining India's energy policy paradox using non-western philosophy, Energy Res. Social Sci. 49 (2019) 16–25.
[83] I. Monasterolo, M. Raberto, The impact of phasing out fossil fuel subsidies on the low-carbon transition, Energy Pol. 124 (2019) 355–370.
[84] A. Serrano-Jiménez, J. Lizana, M. Molina-Huelva, Á. Barrios-Padura, Decision-support method for profitable residential energy retrofitting based on energy-related occupant behaviour, J. Clean. Prod. 222 (2019) 622–632.
[85] W.-M. Chen, H. Kim, Circular Economy and Energy Transition: A Nexus Focusing on the Non-energy Use of Fuels, vol. 30, Energy & Environment, 2019, pp. 586–600.
[86] Y.J. Baek, T.Y. Jung, S.J. Kang, Low carbon scenarios and policies for the power sector in Botswana, Clim. Pol. 19 (2019) 219–230.
[87] O. Kraan, S. Dalderop, G.J. Kramer, I. Nikolic, Jumping to a better world: an agent-based exploration of criticality in low-carbon energy transitions, Energy Res. Social Sci. 47 (2019) 156–165.
[88] M.J. Ivanov, Governed by tensions: the introduction of renewable energies and their integration in the Bulgarian energy system (2006–2016), Environ. Innov. Soc. Transit. 32 (2019) 90–106.
[89] T. Nochta, C. Skelcher, Network governance in low-carbon energy transitions in European cities: a comparative analysis, Energy Pol. 138 (2020), 111298.
[90] P. Huang, P. Li, Politics of urban energy transitions: new energy vehicle (NEV) development in Shenzhen, China, Environ. Polit. 29 (2020) 524–545.
[91] Y. Wen, B. Cai, X. Yang, Y. Xue, Quantitative analysis of China's Low-Carbon energy transition, Int. J. Electr. Power Energy Syst. 119 (2020), 105854.
[92] X. Wu, S. Zhao, Y. Shen, H. Madani, Y. Chen, A combined multi-level perspective and agent-based modeling in low-carbon transition analysis, Energies 13 (2020) 5050.
[93] T. Li, P. Liu, Z. Li, Quantitative relationship between low-carbon pathways and system transition costs based on a multi-period and multi-regional energy infrastructure planning approach: a case study of China, Renew. Sustain. Energy Rev. 134 (2020), 110159.
[94] Z. Hu, When energy justice encounters authoritarian environmentalism: the case of clean heating energy transitions in rural China, Energy Res. Social Sci. 70 (2020), 101771.
[95] H. Zhang, X. Zhang, J. Yuan, Transition of China's power sector consistent with Paris agreement into 2050: pathways and challenges, Renew. Sustain. Energy Rev. 132 (2020), 110102.
[96] M. Deleidi, M. Mazzucato, G. Semieniuk, Neither crowding in nor out: public direct investment mobilising private investment into renewable electricity projects, Energy Pol. 140 (2020), 111195.
[97] D. Ioannidou, G. Sonnemann, S. Suh, Do we have enough natural sand for low-carbon infrastructure? J. Ind. Ecol. 24 (2020) 1004–1015.
[98] G. Bachner, B. Wolkinger, J. Mayer, A. Tuerk, K.W. Steininger, Risk assessment of the low-carbon transition of Austria's steel and electricity sectors, Environ. Innov. Soc. Transit. 35 (2020) 309–332.
[99] J. Morrissey, E. Schwaller, D. Dickson, S. Axon, Affordability, security, sustainability? Grassroots community energy visions from Liverpool, United Kingdom, Energy Res. Social Sci. 70 (2020), 101698.
[100] C. Pizarro-Irizar, M. Gonzalez-Eguino, W. Van DER Gaast, I. Arto, J. Sampedro, D.-J. Van DE Ven, Assessing stakeholder preferences on low-carbon energy transitions, Energy Sources B Energy Econ. Plann. (2020) 1–37.
[101] S. Bracco, A study for the optimal exploitation of solar, wind and hydro resources and electrical storage systems in the Bormida Valley in the North of Italy, Energies 13 (2020) 5291.
[102] C.P.-S. DE Brauwer, J. Cohen, Analysing the potential of citizen-financed community renewable energy to drive Europe's low-carbon energy transition, Renew. Sustain. Energy Rev. 133 (2020), 110300.
[103] N.S. Ouedraogo, Transition pathways for North Africa to meet its (intended) nationally determined contributions ((I) NDCs) under the Paris agreement: a model-based assessment, Clim. Pol. 20 (2020) 71–94.
[104] Y. Simsek, H. Sahin, Á. Lorca, W.G. Santika, T. Urmee, R. Escobar, Comparison of energy scenario alternatives for Chile: towards low-carbon energy transition by 2030, Energy 206 (2020), 118021.
[105] G.S. Seck, E. Hache, C. Bonnet, M. Simoën, S. Carcanague, Copper at the crossroads: assessment of the interactions between low-carbon energy transition and supply limitations, Resour. Conserv. Recycl. 163 (2020), 105072.
[106] M. Martiskainen, B.K. Sovacool, A. Hook, Temporality, consumption, and conflict: exploring user-based injustices in European low-carbon transitions, Technol. Anal. Strat. Manag. 33 (2021) 770–782.
[107] G. Siciliano, L. Wallbott, F. Urban, A.N. Dang, M. Lederer, Low-carbon Energy, Sustainable Development, and Justice: towards a Just Energy Transition for the Society and the Environment, Sustainable Development, 2021.
[108] B.K. Sovacool, D.J. Hess, R. Cantoni, Energy transitions from the cradle to the grave: a meta-theoretical framework integrating responsible innovation, social practices, and energy justice, Energy Res. Social Sci. 75 (2021), 102027.
[109] K. Dong, Q. Jiang, M. Shahbaz, J. Zhao, Does low-carbon energy transition mitigate energy poverty? The case of natural gas for China, Energy Econ. 99 (2021), 105324.
[110] S. Bai, B. Zhang, Y. Ning, Y. Wang, Comprehensive analysis of carbon emissions, economic growth, and employment from the perspective of industrial restructuring: a case study of China, Environ. Sci. Pollut. Control Ser. (2021) 1–23.
[111] P. Huang, When government-led experimentation meets social resistance? A case study of solar policy retreat in Shenzhen, China, Energy Res. Social Sci. 75 (2021), 102031.
[112] S.Y. Kim, K. Ganesan, P. Dickens, S. Panda, Public sentiment toward solar energy—opinion mining of twitter using a transformer-based language model, Sustainability 13 (2021) 2673.
[113] L. Silva, S. Sareen, Solar photovoltaic energy infrastructures, land use and sociocultural context in Portugal, Local Environ. 26 (2021) 347–363.
[114] Y. Peng, X. Bai, Financing urban low-carbon transition: the catalytic role of a city-level special fund in shanghai, J. Clean. Prod. 282 (2021), 124514.
[115] N. Dunz, A. Naqvi, I. Monasterolo, Climate sentiments, transition risk, and financial stability in a stock-flow consistent model, J. Financ. Stabil. 54 (2021), 100872.
[116] A. Millot, N. Maïzi, From open-loop energy revolutions to closed-loop transition: what drives carbon neutrality? Technical Forecasting and Social Change 172 (2021), 121003.
[117] A. Novikau, What does energy security mean for energy-exporting countries? A closer look at the Russian energy security strategy, J. Energy Nat. Resour. Law 39 (2021) 105–123.
[118] J. Markard, D. Rosenbloom, Political conflict and climate policy: the European emissions trading system as a Trojan Horse for the low-carbon transition? Clim. Pol. 20 (2020) 1092–1111.
[119] D.N. Janssen, E.P. Ramos, V. Linderhof, N. Polman, C. Laspidou, D. Fokkinga, D. DE Mesquita E Sousa, The climate, land, energy, water and food nexus challenge in a land scarce country: innovations in The Netherlands, Sustainability 12 (2020), 10491.
[120] J. Baran, A. Szpor, J. Witajewski-Baltvilks, Low-carbon transition in a coal-producing country: a labour market perspective, Energy Pol. 147 (2020), 111878.
[121] M.A. Alomari, R.J. Heffron, Utilising law in the transition of the Kingdom of Saudi Arabia to a low-carbon economy, Environ. Innov. Soc. Transit. 39 (2021) 107–118.

[122] D. Streimikiene, G.L. Kyriakopoulos, V. Lekavicius, I. Siksnelyte-Butkiene, Energy poverty and low carbon just energy transition: comparative study in Lithuania and Greece, Soc. Indicat. Res. (2021) 1–53.
[123] J. Tian, L. Yu, R. Xue, S. Zhuang, Y. Shan, Global low-carbon energy transition in the post-COVID-19 era, Appl. Energy 307 (2022), 118205.
[124] Y.J. Kim, M. Soh, S.-H. Cho, Identifying optimal financial budget distributions for the low-carbon energy transition between emerging and developed countries, Appl. Energy 326 (2022), 119967.
[125] L. Pingkuo, P. Huan, What drives the green and low-carbon energy transition in China?: an empirical analysis based on a novel framework, Energy 239 (2022), 122450.
[126] S.D. Agyeman, B. Lin, Nonrenewable and renewable energy substitution, and low–carbon energy transition:Evidence from North African countries, Renew. Energy 194 (2022) 378–395.
[127] S. Luo, S. Zhang, How R&D expenditure intermediate as a new determinants for low carbon energy transition in Belt and Road Initiative economies, Renew. Energy 197 (2022) 101–109.
[128] Y. Xiao, H. Yang, Y. Zhao, G. Kong, L. Ma, Z. Li, W. Ni, A comprehensive planning method for low-carbon energy transition in rapidly growing cities, Sustainability 14 (2022) 2063.
[129] K. Govindan, Pathways to low carbon energy transition through multi criteria assessment of offshore wind energy barriers, Technical Forecasting and Social Change 187 (2023), 122131.
[130] Y. Liu, X. Dong, K. Dong, Pathway to prosperity? The impact of low-carbon energy transition on China's common prosperity, Energy Econ. (2023), 106819.
[131] X. Wang, X. Sun, M. Ahmad, H. Zhang, Does low carbon energy transition impede air pollution? Evidence from China's coal-to-gas policy, Resour. Pol. 83 (2023), 103723.
[132] D. Werner, L.L.B. Lazaro, The policy dimension of energy transition: the Brazilian case in promoting renewable energies (2000–2022), Energy Pol. 175 (2023), 113480.
[133] Y. Feng, J. Zhang, Y. Geng, S. Jin, Z. Zhu, Z. Liang, Explaining and modeling the reduction effect of low-carbon energy transition on energy intensity: empirical evidence from global data, Energy (2023), 128276.
[134] Y. Tan, X. Ying, W. Gao, S. Wang, Z. Liu, Applying an extended theory of planned behavior to predict willingness to pay for green and low-carbon energy transition, J. Clean. Prod. 387 (2023), 135893.
[135] M. Speich, S. Ulli-Beer, Applying an ecosystem lens to low-carbon energy transitions: a conceptual framework, J. Clean. Prod. 398 (2023), 136429.
[136] F. Chien, T.L. Vu, T.T.H. Phan, S. Van Nguyen, N.H.V. Anh, T.Q. Ngo, Zero-carbon energy transition in ASEAN countries: the role of carbon finance, carbon taxes, and sustainable energy technologies, Renew. Energy 212 (2023) 561–569.
[137] C. Wang, Low-carbon transition toward green recovery: policy framework after COVID-19, Econ. Change Restruct. (2023) 1–21.
[138] A. Smith, A. Stirling, Moving outside or inside? Objectification and reflexivity in the governance of socio-technical systems, J. Environ. Pol. Plann. 9 (2007) 351–373.
[139] E. Shove, G. Walker, Caution! Transitions ahead: politics, practice, and sustainable transition management, Environ. Plann. 39 (2007) 763–770.
[140] M. Lawhon, J.T. Murphy, Socio-technical regimes and sustainability transitions: insights from political ecology, Prog. Hum. Geogr. 36 (2012) 354–378.
[141] P. Späth, H. Rohracher, Local demonstrations for global transitions—dynamics across governance levels fostering socio-technical regime change towards sustainability, Eur. Plann. Stud. 20 (2012) 461–479.
[142] N. Eyre, S.J. Darby, P. Grünewald, E. Mckenna, R. Ford, Reaching a 1.5 C target: socio-technical challenges for a rapid transition to low-carbon electricity systems, Phil. Trans. Math. Phys. Eng. Sci. 376 (2018), 20160462.
[143] N. Jung, M.E. Moula, T. Fang, M. Hamdy, R. Lahdelma, Social acceptance of renewable energy technologies for buildings in the Helsinki Metropolitan Area of Finland, Renew. Energy 99 (2016) 813–824.
[144] T. Haukkala, Does the sun shine in the High North? Vested interests as a barrier to solar energy deployment in Finland, Energy Res. Social Sci. 6 (2015) 50–58.
[145] E. Heaslip, F. Fahy, Developing transdisciplinary approaches to community energy transitions: an island case study, Energy Res. Social Sci. 45 (2018) 153–163.
[146] E.H. Klijn, J. Koppenjan, Governance Networks in the Public Sector, Routledge, 2015.
[147] S. Pye, P.-H. Li, I. Keppo, B. O'Gallachoir, Technology interdependency in the United Kingdom's low carbon energy transition, Energy Strategy Rev. 24 (2019) 314–330.
[148] L. Hughes, J. Urpelainen, Interests, institutions, and climate policy: explaining the choice of policy instruments for the energy sector, Environ. Sci. Pol. 54 (2015) 52–63.
[149] R. Kemp, J. Rotmans, D. Loorbach, Assessing the Dutch energy transition policy: how does it deal with dilemmas of managing transitions? J. Environ. Pol. Plann. 9 (2007) 315–331.
[150] M.Y. Suberu, M.W. Mustafa, N. Bashir, N.A. Muhamad, A.S. Mokhtar, Power sector renewable energy integration for expanding access to electricity in sub-Saharan Africa, Renew. Sustain. Energy Rev. 25 (2013) 630–642.
[151] K.A. Munir, Being different: how normative and cognitive aspects of institutional environments influence technology transfer, Hum. Relat. 55 (2002) 1403–1428.
[152] L. Baker, J. Phillips, Tensions in the transition: the politics of electricity distribution in South Africa, Environ. Plan. C Politics Space 37 (2019) 177–196.
[153] J. Meadowcroft, Let's get this transition moving, Can. Publ. Pol. 42 (2016) S10–S17.
[154] D. Tyfield, Transportation and Low Carbon Development. Low Carbon Development, Routledge, 2013.
[155] C. Demski, C. Butler, K.A. Parkhill, A. Spence, N.F. Pidgeon, Public values for energy system change, Global Environ. Change 34 (2015) 59–69.
[156] J. Barry, G. Ellis, Beyond consensus? Agonism, republicanism and a low carbon future, Renewable energy and the public, 29-42, (2014) Routledge.
[157] K. Jenkins, D. Mccauley, R. Heffron, H. Stephan, R. Rehner, Energy justice: a conceptual review, Energy Res. Social Sci. 11 (2016) 174–182.
[158] D.A. Mccauley, R.J. Heffron, H. Stephan, K. Jenkins, Advancing energy justice: the triumvirate of tenets, International Energy Law Review 32 (2013) 107–110.
[159] B.K. Sovacool, R.J. Heffron, D. Mccauley, A. Goldthau, Energy decisions reframed as justice and ethical concerns, Nat. Energy 1 (2016) 1–6.
[160] D. Mccauley, V. Ramasar, R.J. Heffron, B.K. Sovacool, D. Mebratu, L. Mundaca, Energy Justice in the Transition to Low Carbon Energy Systems: Exploring Key Themes in Interdisciplinary Research, Elsevier, 2019.
[161] A.G. LA Viña, J.M. Tan, T.I.M. Guanzon, M.J. Caleda, L. Ang, Navigating a trilemma: energy security, equity, and sustainability in the Philippines' low-carbon transition, Energy Res. Social Sci. 35 (2018) 37–47.
[162] B.K. Sovacool, H. Saunders, Competing policy packages and the complexity of energy security, Energy 67 (2014) 641–651.
[163] L. Hughes, The four 'R's of energy security, Energy Pol. 37 (2009) 2459–2461.
[164] D. Mikulić, D. Keček, Investments in Croatian RES plants and energy efficient building retrofits: substitutes or complements? Energies 15 (2021) 2.
[165] T. Gelo, N. Šimurina, J. Šimurina, The economic impact of investment in renewables in Croatia by 2030, Energies 14 (2021) 8215.
[166] J. Curtin, C. Mcinerney, L. Johannsdottir, How can financial incentives promote local ownership of onshore wind and solar projects? Case study evidence from Germany, Denmark, the UK and Ontario, Local Econ. 33 (2018) 40–62.
[167] Ş. KıLKıŞ, G. Krajačić, N. Duić, M.A. Rosen, Accelerating Mitigation of Climate Change with Sustainable Development of Energy, Water and Environment Systems, Elsevier, 2021.
[168] D. Streimikiene, A. Mikalauskiene, M. Kamali Saraji, A. Mardani, Framework for assessment of climate change mitigation policies impact on just transition towards low carbon future, Handbook of Climate Change Mitigation and Adaptation, Springer, 2022, pp. 3115–3148.
[169] K. Johansen, Blowing in the wind: a brief history of wind energy and wind power technologies in Denmark, Energy Pol. 152 (2021), 112139.
[170] K.E. Rignall, Solar power, state power, and the politics of energy transition in pre-Saharan Morocco, Environ. Plann.: Econ. Space 48 (2016) 540–557.
[171] S.M. Borras JR., J.C. Franco, Global land grabbing and political reactions 'from below, Third World Q. 34 (2013) 1723–1747.
[172] J. Fairhead, M. Leach, I. Scoones, Green grabbing: a new appropriation of nature? J. Peasant Stud. 39 (2012) 237–261.
[173] W. Mrozik, M.A. Rajaeifar, O. Heidrich, P. Christensen, Environmental impacts, pollution sources and pathways of spent lithium-ion batteries, Energy Environ. Sci. 14 (2021) 6099–6121.
[174] S. Samadder, R. Prabhakar, D. Khan, D. Kishan, M. Chauhan, Analysis of the contaminants released from municipal solid waste landfill site: a case study, Sci. Total Environ. 580 (2017) 593–601.
[175] A. Goldthau, K. Westphal, Why the global energy transition does not mean the end of the petrostate, Global Policy 10 (2019) 279–283.
[176] P. Kivimaa, M.H. Sivonen, Interplay between low-carbon energy transitions and national security: an analysis of policy integration and coherence in Estonia, Finland and Scotland, Energy Res. Social Sci. 75 (2021), 102024.
[177] P. Johnstone, K.S. Rogge, P. Kivimaa, C.F. Fratini, E. Primmer, Exploring the re-emergence of industrial policy: perceptions regarding low-carbon energy transitions in Germany, the United Kingdom and Denmark, Energy Res. Social Sci. 74 (2021), 101889.
[178] A. Grubler, C. Wilson, G. Nemet, Apples, oranges, and consistent comparisons of the temporal dynamics of energy transitions, Energy Res. Social Sci. 22 (2016) 18–25.
[179] F. Kern, K.S. Rogge, Harnessing theories of the policy process for analysing the politics of sustainability transitions: a critical survey, Environ. Innov. Soc. Transit. 27 (2018) 102–117.
[180] G.F. Nemet, M. Jakob, J.C. Steckel, O. Edenhofer, Addressing policy credibility problems for low-carbon investment, Global Environ. Change 42 (2017) 47–57.
[181] J.D. Hunt, B. Zakeri, J. Jurasz, P. Dąbek, R. Brandão, E.R. Patro, B. Durin, W. Leal Filho, Y. Wada, B. Van Ruijven, Underground Gravity Energy Storage: A Solution for Long-Term Energy Storage,*16*(2), 825, (2022) Available at: SSRN 4184471.