EJNMMI Physics

https://doi.org/10.1007/s43621-025-02552-4

Article in Press

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Received: 11 August 2025

Accepted: 15 December 2025

Published online: 01 April 2026

Cite this article as: Alka T.A., Suresh M. & Raman R. Pathways of sustainable energy entrepreneurship contributing to green innovation and the sustainable development goals. ***EJNMMI Phys*** **(2026). https://doi.org/10.1007/s43621-025-02552-4**

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Pathways of sustainable energy entrepreneurship contributing to green innovation and the Sustainable Development Goals

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Abstract: This study examines sustainable energy entrepreneurship (SEE) by exploring global patterns, drivers, and barriers that influence entrepreneurial journeys toward green innovation and societal impact. SEE research lacks an integrated, multi-theoretical, cross-context synthesis explaining how technical, institutional, social, gender, and resilience factors influence. This study addresses this gap with a first theory-informed, multi-dimensional synthesis that brings domains together. Through a structured, systematic literature review guided by PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) for document selection, keyword co-occurrence analysis, and thematic organization via the TCCM (Theory, Context, Characteristics, Methods) framework. The study applies the ADO (antecedent-decision-outcome) framework to propose future research directions. The results reveal five major themes: (1) institutional entrepreneurship and governance, (2) resilience to externalities, (3) gender and stakeholder inclusion, (4) technological innovations in energy systems, and (5) inclusive, adaptive business models. These are mapped to the United Nations Sustainable Development Goals: SDG 7 (enhancing energy access), SDG 5 (gender equality through women's empowerment), SDG 9 (technological innovation development), SDG 10 (social inclusion), SDG 13 (climate change mitigation), and SDG 17 (improving partnerships). This study highlights the need for integrated institutional, gender-inclusive policy frameworks, resilient business models, and technology-based decentralization for green entrepreneurial ecosystems. This study offers implications for policymakers and practitioners by identifying SEE as a driver of sustainable and inclusive growth, the urgency for developing competencies, and innovation ecosystems to support equitable and climate-resilient energy transitions. The study also identified that future research should focus on multidimensional approaches linked to sustainability, inclusion, and innovation.

Keywords: Sustainable energy; Entrepreneurship; Energy transition; Renewable energy; Resilience; Sustainable development goals

1. Introduction

The sustainable energy transition is one of the urgent needs of the 21st century in light of the targets of climate change mitigation, energy access, and inclusive sustainable economic development [1, 2]. Sustainable energy entrepreneurship (SEE) has emerged as a catalyst for meeting the energy demand of marginalized populations where traditional energy systems fail [3]. SEE accelerates innovation and energy access and promotes inclusive development in both developed and developing nations through the establishment of clean, inclusive, and context-efficient sustainable energy solutions [4]. The decentralized entrepreneurial practices promoted by SEEs that merge social and environmental commitments with business objectives accelerate the global sustainable energy transition [5, 6].

Entrepreneurs in the sustainable energy sector ensure renewable energy production by utilizing commercial infrastructure, research, and development transfer, which leads to an increase in the share of the global energy mix, contributing to the United Nations Sustainable Development Goal [4]. Sustainable Energy Entrepreneurship (SEE) is advancing SDG 7 by expanding access to affordable and clean energy through decentralized solutions, technological innovation, and context-appropriate renewable energy models. Through clean energy provision for underserved communities and supporting the transition toward low-carbon systems, SEE contributes directly to the global clean-energy targets while promoting inclusive and sustainable development [3]. Energy policies are also aligned with micro, macro, and meso-level sustainability [7, 8]. Similarly, Zaghdoud [9] reported that sustainable energy encompasses technological and green practices, contributes to achieving the SDG agenda, focuses on SDG 8 and SDG 13, and emphasizes both inclusive economic development and environmental responsibility. Solangi and Magazzino [10] show the economic dimensions of renewable energy adoption by promoting financial viability, social advantages, and economic sustainability, aligning with SDG 13 and SDG 17 through strategies that include green finance and public–private partnerships by entrepreneurs in the energy sector. These findings underscore the crucial role of SEE in achieving sustainability targets, thereby facilitating renewable energy transitions.

Recent studies highlight technological innovations, the need for decentralization, community development, and the metamorphoses of current institutional settings, which are clearly identified in Table 1. SEE is essential for ensuring energy access, technological innovation, and socially inclusive, equitable energy transitions. The existing literature examined the domains in a fragmented way around technological, institutional, financial, and social. Entrepreneurial innovation is a required component of energy systems. Baquero & Monsalve [11] and Boujelbene et al. [12] investigated the entrepreneurs' contribution to the development of the hydrogen and fuel-cell innovations, which are a scalable alternative to conventional systems. This technology-oriented focus is not linked with the track of governance, market, or social inclusion factors. Likewise, there are barriers concerning the commercialization by startups in the scaling of the hydrogen systems and other clean technologies [13,14].

Table 1. Synthesis of review papers

Reference	**Focus area**	**Key findings**	**Method**	**Number of Studies included and the search period**	**Search terms**
Bendig et al. [15]	Types, characteristics, and sustainability impacts of renewable	Renewable-energy start-ups face issues with demand, strategic approaches, and even though they are decarbonization and energy access. There is a need for clear, targeted rural	Systematic literature review	142 articles from Scopus without a time limit	"entrepreneur∗", "energ∗" and one of the following to describe renewable energy: "batter∗", "biofuel", "biogas", "clean", "geothermal", "hydro", "ocean", "renewable", "solar", "storage", "tide",

	energy entrepreneurship	entrepreneurship policies.			"wave", "wind". ("new business model" OR "business innovation" OR "business concept" OR "market entry").
Goyal et al. [16]	Public policy in energy transitions research	Public policy concepts like policy entrepreneurship, diffusion, and success are less explored, and gaps in the policy innovation in energy transition.	Bibliometric review and computational text	8442 documents from Social Sciences Citation Index (SSCI) and the Book Citation Index-Social Sciences and Humanities (BKCI-SSH) up to July 05, 2021	(electricity OR energy OR “power generation” OR “power system*” OR renewable OR smartgrid OR “smart grid*”) AND (MLP OR “multilevel perspective” OR SNM OR “strategic niche management” OR “technological innovation system*” OR TIS OR transition) NOT (“demographic transition*” OR “energy intake” OR “land?cover transition*” OR “land?use transition*” OR “nutrition transition*” OR “phase transition*”)
Nepal et al., [17]	Blockchain implementation in smart energy	Scalability, regulatory framework, cybersecurity, operational cost, interoperability, etc, are operational challenges, and the cost overhead, and time lag during payment and conversions are the transactional challenges	Systematic literature review	55 articles from Google Scholar as of 15 October 2021 in Google Scholar	“Blockchain in smart energy”, “Renewable energy and Blockchain”, and “Blockchain and transactive energy”
Romero-Castro et al. [18]	Entrepreneurship promotes the Development of Community Renewable Energy in Rural	Economic, human, social, physical, and natural are the major antecedent factors	Systematic Literature Review	87 articles related to renewable energy technologies and 89 related to renewable energy from Scopus up to March 2018	“rural AND renewable energy” and “rural AND entrepreneurship”

	Areas				
Gabriel [19]	Challenges faced by renewable energy entrepreneurs in developing countries	Challenges are: inadequate access to institutional finance; the price of renewable energy technologies; infrastructure and logistics; inadequate government or policy support	Qualitative meta-analytic methods	499 articles published since 1990 from ProQuest Central, Academic OneFile, Business Source Complete, Academic Search Complete, Scopus, Science Direct, and Web of Science databases	(“renewable energy” AND “entrepreneur*”), renewable energy challenges (search terms “renewable energy” AND “challenge” OR “constraint”), and entrepreneurship challenges (search terms “entrepreneur*” AND “challenge” OR “constraint”)

Institutional limitations are constraints on entrepreneurial scalability. The policy scatter in the context of Bangladesh constraints the growth of solar and off-grid systems. However, this examination by Munjer et al. [20] does not consider the integration of the institutional barriers with entrepreneurial behaviour, local agency, or technology adoption. The context-oriented solution, which integrates local resources, governance needs, and technological adaptation [3], can be accelerated by the SEE. These studies consider these aspects independently rather than comprehensively. Bendig et al. [15] conducted a systematic review of renewable energy entrepreneurship, identifying the types of ventures and their sustainability impacts, as well as demand-oriented deficit barriers and strategic-level constraints. This highlights the need for targeted rural entrepreneurship policies, but does not consider the case of start-ups, nor does it examine governance, gender, or institutional embeddedness.

Likewise, Goyal et al. [16] review public policy in energy transitions and identify that core innovation policy concepts like policy entrepreneurship, diffusion, and success are less applied. This limited focus only to policy transitions, not covering the sustainable energy entrepreneurship, and does not connect policy innovation with entrepreneurial action or community-level actual realities. The adoption of blockchain in the smart energy system is examined by Nepal et al. [17] highlighted that there are operational and transactional challenges. However, these challenges examination focuses more on the technological side and lacks the institutional, social, or entrepreneurial dynamics. In addition to this, Romero-Castro et al. [18] analyse rural community renewable energy and found that economic, human, social, physical, and natural antecedents. This limited focus on rural areas in developed countries does not integrate entrepreneurial strategy, gender, or technology innovation. The renewable energy entrepreneurs are facing constraints in terms of the technology, process of energy systems, lack of labor, lack of good logistics, and less policy assistance and support, are highlighted by Gabriel [19]. This emphasizes only the challenge taxonomy, lacking the link with institutional behaviour, innovation systems, or inclusive entrepreneurship.

From these reviews, there is a clear picture that there is no existing synthesis that integrates technology, institutional dynamics, entrepreneurial agency, gender inclusion, resilience, and market readiness into a single analytical framework. This focus is either on narrow sectors like blockchain or hydrogen, in the context of the only policy or rural development, or a catalogue of barriers or challenges or entrepreneurial types, without linking them to multi-level transition theories. This lack of integration reveals that SEE is currently explored through independent or isolated theoretical and contextual lenses, even though SEE operates at the intersection of institutional behaviour, technological systems, social inclusion, and market dynamics. Hence, this research examination combines these individual lenses into an integrated synthesis of SEE research.

Along with this, there are reviews which highlight the individual contributions focusing on the microfinance-based women's empowerment in Gatto [21], PPP-enabled governance systems in Kolk & van [22], national innovation system evidence in Karimi et al. [4], urban civic entrepreneurship in Tomor [23], digital peer-to-peer platforms in Valsan et al. [24], and spin-off commercialization directions in Nejabat & Geenhuizen [25]. These also highlight the focus on singular dimensions. The current research either concentrates on technological development, governance mechanisms, gender, or community participation, without offering cross-domain theoretical integration. Likewise, there is a lack of integrated theoretical foundations rather as Gning & Muchapondwa [26] explored through gender-based entrepreneurial resilience under energy externalities, but these findings are not situated within strategic entrepreneurship or innovation-system frameworks. This is also limiting the cumulative knowledge-building and lacking the multi-level mechanisms driving SEE. Hence, this research fills this theoretical gap through the integrated theoretical foundations connecting with the SEE, bridging the gap of a lack of an integrated model rather than an isolated focus in the previous research.

Therefore, a lack of integrated, multi-theoretical, cross-context synthesis explaining how technical, institutional, social, gender, market, and resilience factors combinedly influence sustainable energy entrepreneurship globally is a theoretical gap filled by this research. From these, the study was motivated and the first research providing the global, theory-informed, multi-dimensional synthesis in the most important and emerging field of SEE into a cohesive framework. It clarifies the isolated focus of prior research, identifies key theoretical blind spots, highlights cross-sectoral dynamics, and develops a comprehensive agenda for contributing to SEE research and practice. The interdisciplinary nature of entrepreneurship in different areas, such as development studies, policy analysis, gender studies, and engineering, reveals the scope of such transitions [27]. Policy support is another motivation for providing strong recommendations for sustainable energy transitions. Future research has great potential and an urgent need to explore SEE rather than a more positively skewed current focus on renewable and green energy entrepreneurship through a structured thematic synthesis.

Along with this, the mapping of the SEE with SDG-aligned outcomes across different geopolitical contexts aims to fill the gap in a consolidated understanding of the antecedents, decisions, and outcomes of SEE in various institutional environments, technological systems, and societal settings. In this research, the SDGs are linked, such as SDG 7 (Affordable and Clean Energy), SDG 5 (Gender Equality), SDG 9 (Industry, Innovation, and Infrastructure), SDG 10 (Reduced Inequalities), SDG 13 (Climate Action), and SDG 17 (Partnerships for the Goals), which cover different aspects of the multidisciplinary nature of innovation, entrepreneurial practices, and energy access, revealing the role of SEE not only in the technological or business lens but also in ensuring impact, equity, and climate change mitigation. Hence, this research presents a comprehensive analysis of the link between Sustainable Energy and the SDGs in terms of entrepreneurial approaches, innovation, policy, and resilience, contributing to a more in-depth synthesis of the promising role of Sustainable Energy. This integrated SDG and SEE research explores the following research questions:

1. RQ1: What thematic patterns characterize Sustainable Energy Enterprises (SEEs) across global contexts, and how do these patterns reflect their

contributions to technological innovation, policy influence, and social inclusion?
2. RQ2: What barriers and enablers influence the success and scalability of SEE models?
3. RQ3: How can insights from thematic analysis inform and guide future SEE research?

In addition to the theoretical gap, the study found that a methodological gap exists in the current SEE research. Existing reviews focus on individual themes or are focused on narrative, non-replicable procedures, not provide cross-study comparability. The reviews on renewable energy or sustainable entrepreneurship have provided important insights, but there are limitations in scope and method. The previous reviews did not provide an integrated a unified analytical lens that connects antecedents, entrepreneurial decisions, and outcomes. Hence, this research combines three complementary methodological frameworks: PRISMA, which ensures transparent, replicable identification and selection of studies [28], and conducts keyword occurrence analysis via VOSviewer to identify thematic clusters. TCCM for mapping and the classification of results through the theoretical foundations, contextual features, entrepreneurial characteristics, and methodological applications for systematic analysis [29,30] and the theoretical foundations, contextual features, entrepreneurial characteristics, and methodological applications [31]; and ADO for systematically link antecedents, decisions, and outcomes to reveal causal influencing structures and future research directions [32]. The integration has not been applied in any previous SEE or renewable energy entrepreneurship review. This combined approach provides a deeper, multi-level synthesis that fills theoretical, contextual, and methodological gaps, developing a more holistic and structured knowledge of SEE at the global level.

Hence, this research contributes to SEE research by helping key stakeholders such as entrepreneurs and investors in terms of major challenges, financial mechanisms, regulatory issues, the need to adopt resilient and adaptable strategies, and policymakers through incorporating multilevel governance and a more supportive entrepreneurial ecosystem, including gender-based planning, encouraging innovation although support schemes, and developing decentralized models linked with the SDGs.

2. Research Methodology

This qualitative exploration involves analyzing SEE research and guiding further research suitable for multidisciplinary and emerging themes where macro-and microlevel conceptual clarity and in-depth understanding are needed [31, 33]. The study adopted the following methods, and the detailed research design is presented in Figure 1.

1. Systematic literature selection through the PRISMA method
2. Bibliometric analysis through VOSviewer to identify intellectual structure and thematic clusters
3. TCCM for the clear, structured synthesis of the theory, context, characteristics, and context lenses.
4. ADO for proposing a future research agenda aligning with the SDGs

2.1 PRISMA

The selection of content for this study follows a transparent, replicable, and structured review process based on the PRISMA protocol, which enables systematic identification of studies [34]. Compared with alternative review frameworks, PRISMA reduces bias and promotes methodological consistency [35, 36]. Its adoption is widely recognized across disciplines, particularly in bibliometric and systematic review research, where it enhances research quality and rigor [35, 37, 38]. The review process begins with the formulation of research questions, followed by scope definition and the development of a search string using relevant keywords. This is applied to selected databases, after which the results are filtered through data cleaning and the removal of duplicates.

Studies are then assessed using predefined inclusion and exclusion criteria to finalize the set of documents for analysis [28]. The PRISMA process proceeds through four key stages: (1) identification, (2) screening, (3) eligibility, and (4) inclusion. The search was conducted on November 26, 2025, capturing documents published between 1991 and 2025. The final set of studies was determined by the applied inclusion and exclusion criteria.

Identification

In this stage of the PRISMA process, the following filtrations are performed:

The selected databases are Scopus and Web of Science, which provide indexed, high-quality, comprehensive coverage covering a variety of interdisciplinary research. These databases reduce the likelihood of missing core and high-quality publications, which is essential for studies such as energy research. These two databases covered manuscripts of IEEE journals and conference proceedings, and Entrepreneurial/Business Databases (e.g., ProQuest, EBSCO, ABI/INFORM). Hence, combining Scopus and Web of Science includes the major entrepreneurship, innovation, and management journals from these platforms, ensuring a lower chance of duplication in the case of a large set of documents, and integrating the publications available through IEEE Xplore, EBSCO, and other entrepreneurial databases. The Boolean operators are available in this database, which is helpful for comprehensive literature research [22, 28, 38].

Search Strategy: The keywords *(("sustainable energy" AND "entrepreneur*") OR ("sustainable energy" AND "startup*") OR ("clean energy entrepreneurship") OR ("clean energy " AND "startup*") OR ("green energy venture*"))* are selected for the search to map the papers on the linking of sustainable energy and entrepreneurship. "Sustainable energy" captures documents on clean, renewable energy sources, and "entrepreneur*" (with a wildcard) identifies papers on entrepreneurship. The "startup" covers the newly established ventures that drive innovation in the sustainable energy sector. Using AND in the ("sustainable energy" AND "entrepreneur") AND *("sustainable energy" AND "startup*")* category will include papers that address both sustainable energy and entrepreneurs in all forms. Likewise, sustainable energy and startups also include all the publications that include both. The “OR” operator is used to identify whether the first search string contains papers or the second search string, which helps in identifying all papers that contain both keywords.

Search period: No special inclusion is followed here. The first published documents were published in 1991. During this search period, 292 papers were available in Scopus, and 137 documents were found in the Web of Science.

Screening

In this second stage, the following criteria were adopted for papers to be screened based on the following document types, language, and duplicates.

Document Types: Peer-reviewed publications from Scopus, such as “Article” (142) and “Review” (21), and “Article” (80) and “Review” (20) from Web of Science were selected. The following types of papers are excluded from Scopus: “Conference paper” (64), “Book chapter” (43), “Book” (8), “Conference review” (6), “Short survey” (3), “Note” (3), “Retracted” (2). Likewise, “Proceeding Paper” (29), “Early Access” (4), and “ Editorial material (4) from Web of Science were not used. This is to ensure a high standard of quality. Hence, from Scopus, 163 documents and 100 from Web of Science were taken into account.

Search language: The language was limited to English in Scopus (n=157), and Web of Science (n=99) globally accepted common language used to ensure readability.

Search language: There are five documents that are published in both Scopus and

Web of Science-indexed journals. Hence, the duplications (n=5) from the manual review are excluded.

In this stage, a total of 251 documents were selected for eligibility check.

Eligibility

The screening of the selected 251 papers was based on the relevance of the theme. From these, the 123 papers that fall under the scope of this research are considered. The themes discussed in the papers are limited to entrepreneurial activities, startup ecosystems, green ventures, clean energy entrepreneurship, business innovations within the sustainable energy context, technical energy innovations with entrepreneurial implications, and the entrepreneurship or startup energy sector, not other sectors such as education or agriculture, to ensure their relevance. However, the excluded papers address entrepreneurial activities not specific to the energy sector; studies on startup ecosystems or business innovations in the sustainable energy sector that do not cover entrepreneurial or startup-based implications; technical energy innovations that do not have an entrepreneurial focus; and entrepreneurship or startup initiatives in other sectors that fall beyond the defined scope of this review on SEE trends. This was done by all the authors through a triangulated review approach. Each author reviewed the studies that were selected and then compared and consolidated our findings, and eliminated the irrelevant papers that fell under the above criteria. Conflicts or differences in classification were resolved through joint discussion after each paper's original text was checked and then moved to a consensus through a collaborative approach emphasizing the reliability and consistency of synthesis.

Inclusion

This is the final stage, in which the selected documents, after applying all the inclusion and exclusion criteria, are considered for analysis. A total of 123 documents were selected for literature exploration at this final stage.

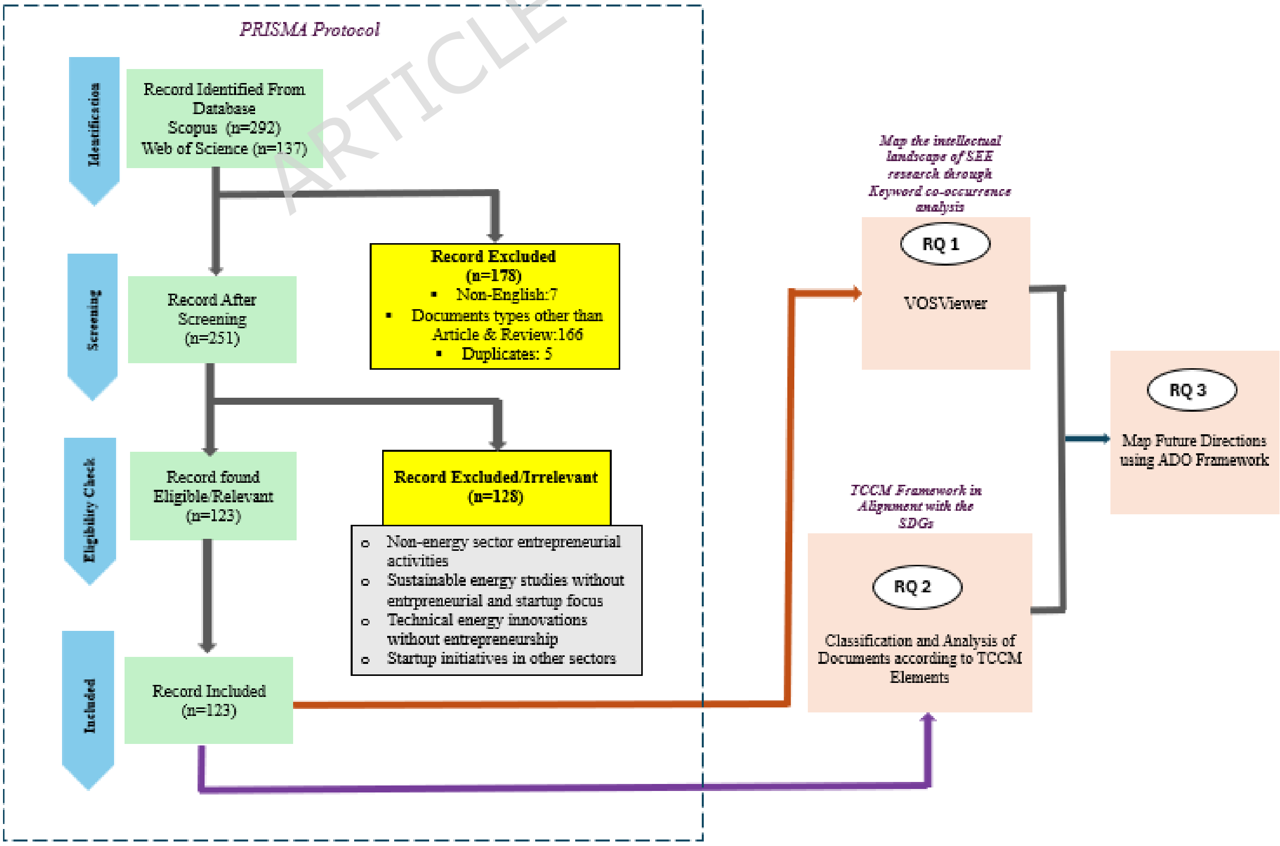

Figure 1. Research methodology

2.2 Bibliometric analysis-VOSviewer

VOSviewer is used for keyword occurrence analysis to understand the intellectual structure of the research domain. VOSviewer is suitable for visualizing bibliometric networks [39]. Keyword co-occurrence analysis based on the authors' keywords is used in this study to understand the keyword clusters based on their frequent appearances, and helps in revealing thematic patterns and topic networks within the field [40]. A threshold of a minimum of three occurrences is set and followed to ensure meaningful representation in the network and clusters. This thematic cluster is further processed with the TCCM framework to systematically interpret SEE research.

2.3 Conceptual Synthesis Using the TCCM Framework

The TCCM is applicable in four dimensions, such as theory, context, characteristics, and methodology, and it is applied for structured literature reviews [35, 23]. This framework is recognized and preferred over the other frameworks in classification [36]. The major highlight is that it helps to inform the future research scope, such as theories mentioning the existing discussed theories and frameworks, contexts explaining the different domains in which the study is undertaken, characteristics indicating the topics discussed, and methods describing the adopted tools and approaches informing further research [30]. TCCM is suitable in the areas characterized by heterogeneous theories, multidisciplinary contexts, and different methodological applications [41- 43]. These TCCM properties in-depth synthesize rather than narrative or chronological reviews in a descriptive nature [28].

SEE research is multi-theoretical nature, in which technology-oriented theories, entrepreneurial theories, management theories, innovation theories, etc, were applicable. TCCM provides a structured way to cluster these theories and highlight the connections between constructs. Likewise, in TCCM, context-based classification is possible, which helps in the systematic comparison of heterogeneous contexts. Here, also, the geographical and sectoral contextual application of SEE can be mapped through context examination [28, 42]. The existing studies highlighted the span of SEEs range in different characteristics such as policy, business models, community and social inclusion, technology adoption, etc. The “Characteristics” dimension of TCCM provides a clear analytical structure for synthesizing these. Along with this, different methodological applications in the SEE research to reveal the pattern and the area were further focused on, and directing further research is also possible in the TCCM.

The TCCM is compatible with other methods like PRISMA [28]. Here, VOSviewer-based keyword co-occurrence clusters synthesized with the TCCM classification of characteristics improve analytical reliability. TCCM allows a replicable and transparent process of synthesis [28]. This classification reduces the descriptive bias and offers theory-linked gap identification. The classification decision is made through the decision protocol by reviewing each selected study consistent with prior TCCM frameworks [29]. They are:

Theory: Identification of theories and classification is done through reviewing each document. During the case of the discussion of multiple theories, the dominant or foundational theory was selected based on interpretation, and the identified theories were classified and grouped by giving weight, and the most important discussed theoretical dimensions were selected.

Context: This is mainly the synthesis by country/region, energy sub-sector (solar, bioenergy, microgrids), and socio-institutional, technological environment.

Characteristics: This is a major focus area in which the classification is done through the innovation processes, policy, financing models, business model development, community participation, gender inclusion, or technology adoption.

Methodology: Each study's research design, like qualitative, quantitative, mixed-methods, econometric modelling, simulation, bibliometric, or conceptual, etc, was reviewed and grouped accordingly. The coding is followed in each process; the authors independently coded each research work through a coding sheet. After this, cross-verification was done, and the resolution of discrepancies was achieved through discussion and re-review of full texts until consensus was achieved. This triangulation approach ensures the reliability of this systematic review process. Hence, this integration ensures systemic examination by quantitative bibliometric mapping and qualitative thematic synthesis, reducing descriptive bias and enhancing interpretive understanding.

Along with this, while synthesizing the existing studies, SDG mapping was conducted in this study, using SciVal's Sustainable Development Goals classification, which helps to identify SDG-relevant publications based on Elsevier's validated SDG algorithm. The initial SDG allotment was done by SciVal and was then manually cross-checked with the thematic content of each included paper to ensure conceptual accuracy. This two-step procedure, through the automated SDG identification, followed by careful manual verification, ensured that the mapped SDGs were reviewed properly.

2.4 Future Research Using the ADO

A framework-based review is essential when performing a literature synthesis [42]. Future research is discussed with the ADO to understand the structural analysis integrated with the TCCM and the relationships that exist in the literature to provide better information. The ADO framework is not a new method; it is applied in different domains, such as IT project success [44], fintech [45], and sustainable social entrepreneurship [28]. Future research could analyze the drivers or antecedents of SEE and the choices indicating decisions and the impacts or outcomes of the last effect. This classification and mapping of its SDGs are achieved through the proposal of research questions, as well as propositions. This approach is essential for theory building [28,31]. The tripartite model provides structured insights into the constructs in the logical sequence, the relationship of how the antecedents influence decisions, and the outcome of the decisions, such as impact [42, 46].

This research also applied the Antecedents-Decisions-Outcomes (ADO) framework to complement the TCCM-based conceptual classification for proposing future research directions. The ADO elements' focus is highlighted below, which is followed before the coding. Antecedents (A) are enablers, drivers, or constraints of the activities of SEE. Decisions (D) are the strategic choices or actions by SEEs. At last, Outcomes (O) are the consequences or effects, or impacts. These are the lenses in which adopted for coding.

A three-step protocol was adopted to extract ADO elements directly from the selected studies. The first step is the systematic examination of each study's abstract, theoretical background, methodology, findings, and discussion sections. Then, the motivations, drivers, or constraints explained in each study were classified as antecedents, entrepreneurial or strategic choices or actions are considered as decisions, and effects, impacts, or consequences are grouped into outcomes. From this, the classification is done in the second stage. The following stage is cross-verification through the review by each author to minimize subjectivity through the cross-check with independent code with re-examining the original text, and discussing until a full consensus is achieved. This triangulated procedure also ensures that there is no identification is done on antecedent, decision, or outcome if it is not mentioned in the original research work. From the TCCM findings, antecedents identified through TCCM-Theory and Context, to second decisions from TCCM-Characteristics, to third and outcomes, extend the TCCM results in a structured direction for future research. Hence, the focus of TCCM describes what contributes to SEE and how it is studied; the

ADO uses these same findings to explain why those factors matter, how entrepreneurs act, and what results those actions produce for future research avenues.

3. Results.

The thematic analysis through the TCCM is discussed in this section, and the synthesis is presented in Figure 5.

3.1. Theories (T)

The sustainable energy transition and SEE cover different theoretical foundations, such as innovation processes, policy influence, and other systemic changes. The theories from the different domains are applicable in SEE research. This is due to the SEE functions at the intersection of technological transition, policy frameworks, market environment, and social inclusion. Therefore, a single theoretical lens is not enough to explain the evolution, emergence, growth, and influence of SEEs for the sustainable energy transitions. For this, this study integrates insights from Institutional Theory, Entrepreneurship and Policy Entrepreneurship Theory, Diffusion of Innovation, the Technological Innovation Systems (TIS) framework, and Feminist Theory.
Here, the following discussion aims to identify the core constructs and to synthesize these theories into an integrated conceptual foundation.

This section explains the major theories (Figure 2).

Institutional Theory

Institutional theory focuses on the influence of structured rules, norms, policies, and organizational culture on decision-making processes and innovation, even at the enterprise level and in public administrations [47]. Inderberg et al. [48] investigated the institutional factors impacting the development of solar photovoltaic solutions in Norway and highlighted the need for strong policy support for innovation in renewable energy strategies. The establishment of a more supportive administrative sector fosters innovation to mitigate systemic change for effective SE transitions. Energy exchange at the interfirm level among industrial districts reveals the institutional policies supporting industrial energy symbiosis. Interfirm collaboration and microgrid facilities for energy trading and sharing through policy support [49,50]. SMEs' creation of competitive advantages by adopting environmentally friendly innovations through the resource-based view is identified by SMEs as proctological. The institutional theory covers how regulatory rules, policy support and incentives, norms, and legitimacy forces influence entrepreneurial behavior and innovation. In SEE, these constructs cover the dimension of how supportive regulations, capacity of administration and leadership, and market-validation policies accelerate entrepreneurs to develop decentralized and renewable energy solutions [47-50]. The legitimacy construct is core, as SEEs require regulatory support to overcome technological and financial problems and uncertainty.

Entrepreneurial Theory and Policy Entrepreneurship Theories

Entrepreneurship theory is the significance of personal and organizational actors in creating change through innovation and strategic decision-making [51]. It includes economic entrepreneurship theory, psychological entrepreneurship theory, sociological entrepreneurship theory, anthropological entrepreneurship theory, opportunity-based entrepreneurship theory, and resource-based entrepreneurship theory [52]. Economic entrepreneurship theory is reflected by Gasbarro et al. [46] in the observation of the role of SEE in public authorities, leading to social and technical transitions aimed at low-carbon energy systems [53]. The analysis highlights the various faces of SEE, such as heroes, visionaries, bandwagoners, and explorers, as per the interaction level with the policy and holding the entrepreneurial agency, which impacts innovation and policy [54]. Chatzinikolaou and Vlados [8] also explored the introduction of new energy policies and their evolution through the lens of policy entrepreneurship in the government and industry, creating policy agendas for the promotion of renewable energy and revealing sociological, opportunity, resource-based, and economic entrepreneurship theories. Policy entrepreneurs are utilizing effort and influence to resolve challenges, create system-level innovations, and encourage sustainable innovation linked with renewable energy projects [55]. This is also related to institutional theory when considering policymakers. From these, it is clear that entrepreneurship theories contribute to constructing a picture of how SEE, including startups, entrepreneurs, or public sector innovators, relate to access and mobilizing resources and creating new energy models such as opportunity recognition, agency, and resource instrumentation [51-55]. Likewise, policy entrepreneurship extends this perspective by revealing how entrepreneurs influence and drive system-level transitions, linking agency to institutional change.

Diffusion of innovation theory

The diffusion of innovation theory is used to examine how renewable energy technologies are adopted among populations. Ajith and Velmurugan [56] adopted this framework to examine factors such as benefits, financial incentives, and the complexity of technology impacting rooftop solar adoption. Their findings also show that government incentives and subsidies, and technical assistance create quick diffusion in microprosumers and align with relative advantages, attributes, and the capability for technology innovation adoption. Hence, the adoption-oriented constructs such as relative advantage, complexity, compatibility, and observability help to cover community-level and household energy adoption patterns. These financial incentives, technological less complicatedness, and improvement in the local awareness influence how SEE innovations such as rooftop solar or microgrids reach across populations [57].

Technological innovation systems (TIS) framework

Alka et al. [3] linked studies on sustainable energy enterprise technology innovation development through quantitative exploration by adopting modeling methods aligned with the TIS function, including search guidance, developing knowledge, and resource mobilization, which are key factors. Wicki & Hansen [57] also relate to the TIS frameworks through market formation, legitimation by connecting the flywheel energy systems in the markets, and the storage of clean energy, leading to diffusion. Biogas technology adopts a system function and is based on actors directly linked to the TIS framework [58]. The acceleration of institutional collaboration by local entrepreneurs was revealed by Tomor [23]. TIS reveals the system-level constructs such as knowledge development, market formation and development, resource mobilization, and legitimation. These constructs clarify or interpreting that how SEEs participate in and enhance innovations like developing local knowledge networks, market entry, or motivating institutional support for emerging new technologies [3,57,58].

Feminist theory

Inequalities, empowerment, reducing gender gaps, and ensuring access to resources are the focus of Gning & Muchapondwa [26], who focused on Senegalese women's energy access through reducing gender gaps. Similarly, eight women-enterprising cases of entrepreneurship in SEEs were examined by Mahajan & Bandyopadhyay [59], which is also linked with feminist theory. Technology trends and gender equality in energy access are also examined by Pearl-Martinez [60]. Feminist theory contributes to the empowerment, resource access, and equity, which reveals that there are gender-related barriers and opportunities within SEE, along with how gender norms, resource inequalities, and intersectional challenges influence women entrepreneurs' engagement in energy entrepreneurship [26,59,60].

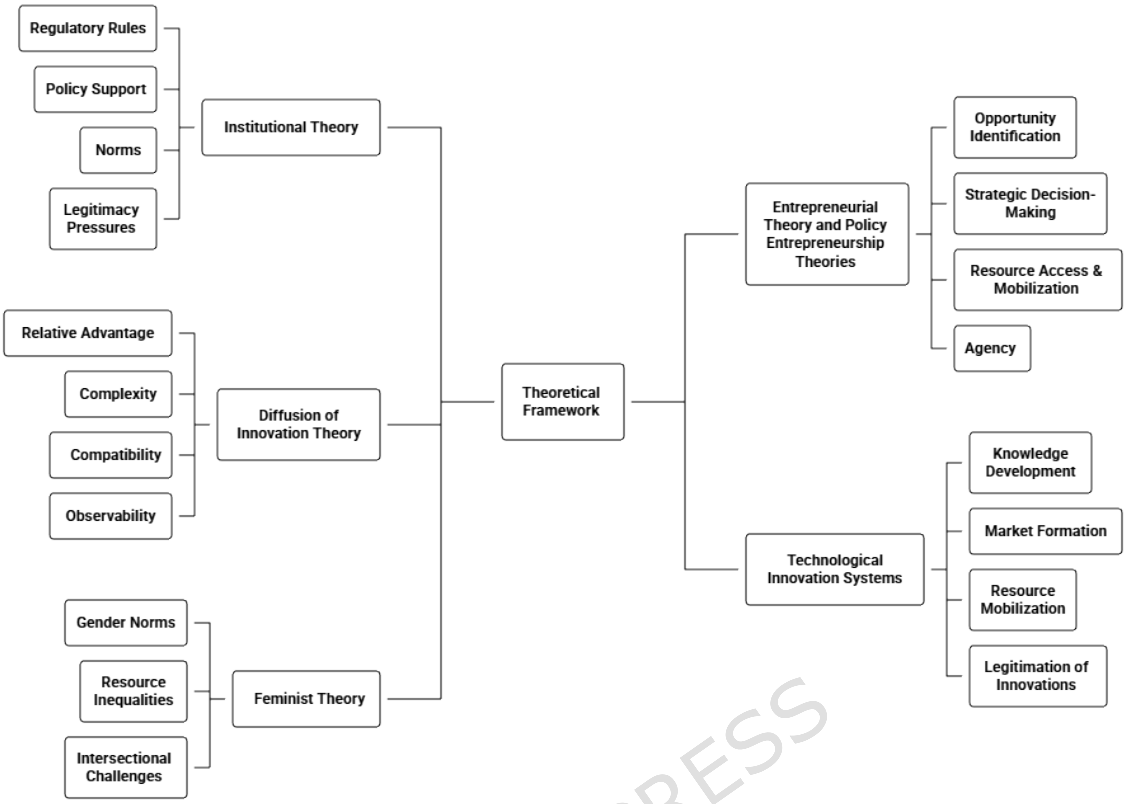

Figure 2. Theoretical framework in SEE

The different theoretical lenses are applied in the SEE research. From the analysis, it is clear that most of the research is focused on the established frameworks such as institutional theory, entrepreneurship theory, diffusion of innovation, and TIS. There is a lack of integrative or cross-theoretical models. The integration of socio-technical, behavioral, and economic theories captures the multi-level transitions, and a few research studies extend or refine existing theories. Gender-based theoretical development is also less than descriptive feminist knowledge. These gaps highlight the requirement for a theory-building, integrated approach in the SEE research. The application of the theories in isolation, without combining the studies, applies single theories in isolation, with little cross-theoretical synthesis to explain the combined institutional, socio-technical, behavioral, and gender-based lens on SEE. The examination reveals fewer of the integrated, holistic, and interdisciplinary theoretical perspectives in SEE research.

3.2. Context (C)

The contexts of the studies are discussed here and presented in Figure 3.

Institutional and Policy Leadership in Energy Innovation

This focuses on governance, agency, and policy entrepreneurship in the context of systematic change at the local and regional levels. The innovation-based administrative settings in the context of Norway in local renewable projects are highlighted by Goyal et al. [16], revealing how institutional and cultural elements influence energy innovations. The Greek context is examined by highlighting policy framework requirements at the micro, macro, and meso levels, revealing the importance of regional local institutional support and policies for developing resilient and SE innovations. The specific focus on the renewable supply chain and discussion of system-based issues, such as policy assistance through subsidies and scalability standard assessment, reveals the supportive policy governance by Almutairi et al. [61]. China's regional policy impact was analyzed by Wang et al. [62] to promote renewable energy utilization in light of supportive policy-market enhancements.

Technological innovation and system modeling for energy systems

Technological innovation is a major element of sustainable energy technologies (SETs). Chai et al. [63] highlighted system model innovations in design through the development of multiphysics models of space nuclear reactors. Baharudin et al. [64] and Nepal et al. [17] highlighted blockchain and digital technologies in smart energy systems, with a focus on operational issues and energy sharing, trading, and other transaction innovations oriented toward security and decentralization. Similarly, Sengupta et al. [65] provide an examination of different contexts through the lens of social entrepreneurship and reveal technological and innovative business models for energy.

Socioeconomic Drivers and Community Engagement in Energy Transition

Stakeholder engagement, community, and social factors influence the adoption of SETs. Tetteh & Kebiret [66] identify the individual and community factors in rooftop solar adoption, which also include government support mechanisms, technical features, and other socioeconomic drivers in the decentralized energy system. Dutta [67] examines the entrepreneurship led by women and their involvement in energy equitable access, promoting empowerment, developing social networks, and enhancing targeted support strategies to scale and ensure the distribution of clean energy. Likewise, Gasbarro et al. [53] identified the collaboration between entrepreneurs and policy authors, revealing social dynamics and a sustainable energy strategy for the development of niche innovations.

Market Dynamics, Commercialization, and Ecosystem Development

The market mechanisms facilitate the scale-up of renewable energy technologies and innovative business models, promoting energy ecosystems relevant to current global sustainability trends [68]. They address the challenges in scaling up renewable technologies via market mechanisms, innovative business models, and energy ecosystems. The meso-level infrastructure is creating an ecosystem approach to sustainable energy transition and a regional market with supportive policy frameworks [8]. Blockchain-based trading in energy markets is crucial for decentralized energy trading, despite operational-level challenges in developing a supportive ecosystem. This highlights the importance of advanced technology adoption and supportive policies for its development.

Environmental, geographic, and resilience challenges

The issues in terms of environmental challenges, geopolitical instability, climate change issues, and the importance of resilience strategies are highlighted by studies in this context [69]. Regional-level hydropower accounts for differences in terms of variability, climate change, and acceptance from society, which are issues and factors influencing the development of climate-resilient energy systems [70]. Saura et al. [71] provide the context of the potential of geothermal and climate resilience, highlighting local adaptation strategies and revealing spatial and environmental considerations and concerns.

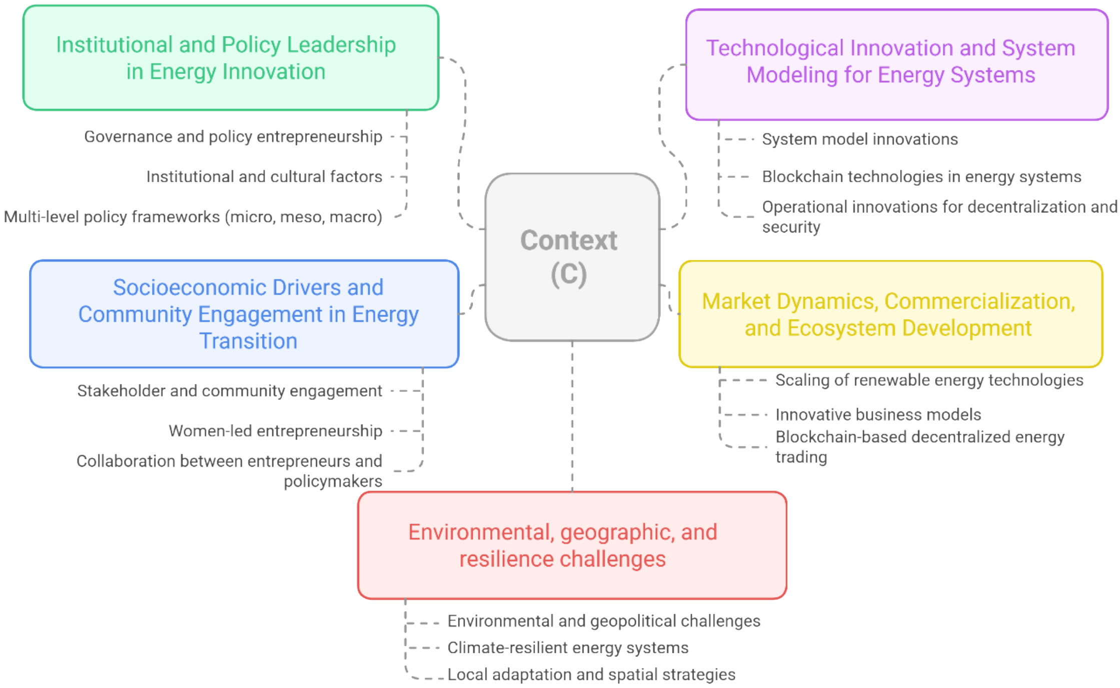

Figure 3. Context in SEE

The examination of existing literature shows that SEE research has mostly explored the contexts of structured policy support, administrative systems operation, and developing technological environments. A smaller number of studies examine SEE in uncertain policy incentives, less institutional capacity, or access to energy based on informal or community-led initiatives. The findings cover the context of institutional, technological, socioeconomic, market, and environmental environments in independence, and there is no integrated analysis other than separately examined. The interaction of these contextual factors and influence, and cross-regional comparisons, is missing. This reveals a scope for research on less-supported environments and integrates different contextual conditions.

3.3. Characteristics (C)

The evolved themes from the keyword occurrence analysis are described below, and cluster analysis is presented in Figure 4.

Theme 1: Institutional Entrepreneurship and Governance in Sustainable Energy Transitions (red)

Institutional frameworks play a central role in shaping sustainable energy (SE) transitions, as they determine the governance systems, policy designs, and entrepreneurial actions that mediate these transformations across spatial scales. Rather than examining individual studies in isolation, a comparative lens reveals how institutional entrepreneurship manifests differently in urban, regional, national, and rural contexts, each with varied outcomes about SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action).

The urban governance dynamics of energy transitions are detailed in Strumińska-Kutra et al. [72], where six European cities illustrate how endogenous agency—local entrepreneurs and officials—responds to exogenous policy mandates by forming networks and financial collaborations. The embeddedness of these actors in institutional designs indicates that successful transitions rely not only on formal policy instruments but also on relational capabilities, which echoes Goyal et al. [16], who argue for the centrality of behavioral and institutional elements in SE policy discourses. Their text analysis shows that technology-led solutions are insufficient without public policy frameworks that foster policy-based entrepreneurship and enable collaboration between academia and practitioners, aligning with SDG 17 (Partnerships for the Goals).

This tension between centralized policy ambition and localized implementation becomes evident in Jolly et al. [73], who examine solar PV deployments in Gujarat and West Bengal under India’s National Solar Mission. Gujarat's success is linked to proactive institutional players and regulatory support, whereas West Bengal's stagnation exposes intracountry governance gaps. This comparative insight aligns with Mallett and Cherniak [74], where decentralized governance in the Canadian Arctic—driven by treaty-based agreements and local autonomy—facilitates energy self-reliance and inclusivity. Both cases highlight the need for flexible governance mechanisms that adapt to regional contexts rather than imposing uniform policies.

These context-sensitive governance dynamics are further problematized in Borges et al. [58], where biogas innovation in Brazil unfolds despite weak policy support and institutional legitimacy. Unlike Gujarat’s top-down coordination, Brazil’s bottom-up innovation underscores how entrepreneurial actors navigate institutional voids, pointing to the significance of market creation and informal coordination as alternatives to formal governance. This contrasts with Munjer et al. [20] on Bangladesh, where ambitious renewable energy plans are hindered by infrastructure constraints and interagency coordination challenges. Here, institutional inertia and fragmented governance reduce the efficacy of policy intentions, despite alignment with development priorities such as SDG 8 (Decent Work and Economic Growth) and SDG 1 (No Poverty).

These examples collectively indicate that institutional entrepreneurship in SE transitions is shaped by varying degrees of coordination, legitimacy, and agency across settings. Rather than being uniformly dependent on policy instruments, the effectiveness of SE transitions is mediated by the interplay between policy entrepreneurs, governance designs, and contextual capacities. Institutional flexibility and multiscalar coordination emerge as recurring elements. Governance for sustainable energy must be not only technically robust but also socially embedded, adaptive, and inclusive to support innovations that address both global climate commitments and localized development needs.

Theme 2: Externalities and Resilience in Sustainable Energy Systems (Green)

Resilience in sustainable energy systems (SEEs) has emerged as a dynamic, cross-cutting construct that is shaped by social, economic, environmental, and technological externalities. The body of research under this theme reflects how resilience is not merely a technological endpoint but also a process driven by anticipation, adaptation, and systemic integration. Through various lenses—ranging from climate disruptions to supply chain risks and institutional frameworks—these studies underscore how SEEs respond to volatility while aligning with SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 13 (Climate Action).

The dual role of perception and response is evident when comparing climate-induced volatility in production systems [70] with the entrepreneurial strategies of SMEs [75]. Saura et al. [71] highlighted how climatic unpredictability creates financial shocks, influencing energy stability and long-term transition pathways. The use of sentiment analysis reveals how reactive systems can become vulnerable in the absence of real-time resilience planning. In contrast, Klemke-Pitek and Majchrzak [75] emphasize proactive behavioral strategies, where SMEs adopt proecological financial logics to maintain resilience through sustainability-focused innovation. Together, these studies illustrate a feedback loop between social perception and adaptive action, wherein resilience is shaped not only by risk but also by anticipatory behavior rooted in socioeconomic rationality.

This social–behavioral orientation connects with the structural and technological considerations explored in Sim et al. [76] and Baharudin et al. [64]. Sim et al. [76] examine shipping enterprises' adaptation through digital infrastructure and sustainable fuels, highlighting how logistical resilience can mitigate disruptions in supply chains. Similarly, Baharudin et al. [64] demonstrated that geological resilience, facilitated by 3D stratigraphic modeling, enhances energy resource forecasting. Together, these studies expand the discourse from reactive social behavior to strategic structural design, showing that resilience requires harmonization between infrastructure modernization and natural resource management, central to SDG 9 and SDG 7.

The policy and planning perspectives further deepen the analysis. Singh [70] addresses administrative and sociopolitical barriers to hydropower development in India's Himalayan region, where externalities such as environmental degradation and governance inefficiencies hinder renewable potential. The contrast between Singh's findings and the technological optimism of Baharudin et al. [64] suggests that resilience planning must bridge technical capabilities with institutional accountability. While modeling can support predictive planning, institutional inertia may limit its translation into practice.

Moya-Clemente et al. [77] adopt a configurational approach to resilience by examining entrepreneurial ecosystems linked to multiple SDGs. Their study illustrates how externalities—when channeled through financial inclusion, ecosystem protection, and infrastructure investment—can generate opportunity configurations rather than vulnerabilities. This systemic framing highlights that resilience is coproduced through multisectoral alignment, where environmental integrity (SDG 15), financial sustainability (SDG 8), and innovation infrastructure (SDG 9) intersect.

Taken together, these studies reveal a layered and interactive model of resilience in SEEs. Saura et al. [71] and Klemke-Pitek & Majchrzak [75] underscore sociobehavioral adaptability; Sim et al. [76] and Baharudin et al. [64] demonstrate structural and technological readiness; Singh [70] highlights institutional constraints; and Moya-Clemente et al. [77] map systemic interlinkages across the SDGs. This collective evidence suggests that resilience must be understood as a continuous process requiring cross-sectoral coordination, multiscalar feedback loops, and SDG-aligned innovation to navigate and transform the externalities shaping sustainable energy systems.

Theme 3: Gender, Women's Entrepreneurship, Stakeholder Inclusion, and Sustainable Energy Access (Blue)

The effectiveness and equity of sustainable energy transitions (SETs) are shaped not only by technological innovations or institutional frameworks but also by the inclusion of local entrepreneurship, community participation, stakeholder collaboration, and gender-sensitive approaches. These elements interact to influence the adoption, impact, and advantage of SETs within diverse contexts, aligning closely with SDG 5 (Gender Equality), SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 10 (Reduced Inequalities), and SDG 11 (Sustainable Cities and Communities).

The role of gender in energy access and participation emerges as a recurring concern. Gning and Muchapondwa [26] demonstrated how participatory strategies in Senegal's PUDC rural electrification program integrated women in decision-making and implementation. The results show shifts in household financial responsibilities and local entrepreneurship, suggesting that gender-equitable energy programs reshape community power dynamics and foster shared agency. These findings resonate with those of Pearl-Martinez [60], who identified that systemic constraints—beyond technological barriers—inhibit women's participation in energy systems. Her policy analysis of six global trends emphasized the need for structural reforms that accommodate women-led entrepreneurship and decentralization, reinforcing energy inclusivity at both the micro and macro levels.

Mahajan and Bandyopadhyay [59] further extended the discourse by examining women-led energy enterprises across three continents. Their analysis highlights how women entrepreneurs develop adaptive business models that reflect local needs while pursuing sustainable energy goals. Despite the persistent challenges of underrepresentation, these enterprises contribute to both service innovation and community-level collaboration. Their work complements the participatory emphasis in Gning and Muchapondwa [26], reinforcing that inclusive entrepreneurship is not peripheral but integral to sustainable development. It also intersects with the economic inclusion goals presented by Gatto [21], who links microfinance with renewable energy transitions. Gatto shows how financial tools serve as enablers for marginalized populations, particularly women, to actively participate in energy development and governance. The integration of economic inclusion with access to energy highlights a pathway toward reducing multidimensional poverty (SDG 1) and enhancing institutional responsiveness (SDG 10).

Participation and inclusivity are also examined through stakeholder and institutional lenses. Matinga et al. [78] emphasize the multiplicity of stakeholder visions in energy strategy development. Their call for culturally grounded and interdisciplinary energy planning stresses that inclusivity extends beyond gender to encompass broader forms of engagement and vision sharing. Meyer and Overen [79] take this further in the South African context, focusing on decentralized governance and entrepreneurship-based models for rural electrification. Their recommendations include the incentivization of local municipalities, training programs, and alignment with higher education to cultivate local skills for energy conservation. This expands the definition of participation to include governance democratization and capacity building, thus creating a bridge between institutional design and community-based energy democracy.

Together, these studies position gender, participation, and inclusive entrepreneurship as intersecting dimensions that codefined the structure and outcomes of SETs. Gning and Muchapondwa [26], Mahajan and Bandyopadhyay [59], and Gatto [21] highlight how gender and finance co-construct inclusive systems, whereas Pearl-Martinez [60] and Meyer and Overen [79] underscore the need for structural and policy transformations. Matinga et al. [73] introduce a broader stakeholder lens, calling attention to pluralism and the integration of multiple types of knowledge in sustainable energy planning. Collectively, these insights indicate that sustainable energy access is not only a technical challenge but also a social process grounded in equity, cooperation, and community agency.

This integrated view reveals that reducing inequalities in energy access and fostering sustainable transitions requires linking gender-based frameworks with entrepreneurial support, stakeholder collaboration, and participatory governance. The development of inclusive SETs must be embedded in broader systems of social and economic empowerment, reinforcing that sustainability depends on distributed agency and locally responsive solutions.

Theme 4: Innovations and advancements in sustainable energy technologies (SETs) (Pea green)

The development of sustainable energy transitions (SETs) is characterized by a complex interplay of technological advancement, financial feasibility, environmental sustainability, and systemic integration. While technical innovation underpins much of the promise of SETs, its adoption and viability are embedded within broader institutional, economic, and social contexts. This theme brings together diverse studies that explore how technological solutions for energy storage, production, and management evolve through entrepreneurial frameworks and systemic coordination, with implications for SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation, and Infrastructure), SDG 13 (Climate Action), and SDG 17 (Partnerships for the Goals).

Challenges related to technological efficiency and environmental constraints are explored through material science innovation. Boujelbene et al. [12] address the thermal instability of PEM fuel cells in subzero environments and propose a passive framework using cascaded multilayer phase change materials (PCMs). Their approach minimizes reliance on external energy inputs, reinforcing the role of technical design in promoting resilient energy systems aligned with low-carbon transitions. This technical emphasis is complemented by da Silva et al. [14], who examined hydrogen production through electrochemical, thermochemical, and biological pathways. Their analysis integrates policy, economic scalability, and external geopolitical conditions, suggesting that technical solutions require multidimensional support structures, including innovation funding and regulatory stability, to be viable at scale.

These case-specific studies converge with the system-level perspectives provided by Wicki and Hansen [57] through the lens of the technological innovation systems (TIS) framework. Their evaluation of flywheel energy storage in the automotive and electricity sectors reveals that institutional support, actor networks, and funding ecosystems are as crucial as the technologies themselves. Even technically viable innovations can falter without market alignment and institutional endorsement. This underscores the need for systemic entrepreneurship that navigates institutional voids and collaborates across public–private boundaries, supporting SDG 17 through cross-sectoral partnerships.

At the intersection of global disparity and technological diffusion, Liu and Liang [80] analyze the bidirectional causality between fossil fuel consumption and innovation capacity. Their findings point to a structural gap between high- and low-income nations, shaped by differentiated policy environments, patent regulation, and digital finance. These disparities suggest that SETs are not homogenous but context-specific processes shaped by the capacity for innovation ecosystem development. Aligning innovation with inclusive growth calls for addressing systemic inequalities, linked with SDG 10 (reduced inequalities).

The shift toward decentralization was explored by Weerakoon and Assadi [81], who applied a technoeconomic model to micro gas turbines (MGTs) and their stabilizing role in renewable-dependent microgrids. Their framework evaluates fuel flexibility and part-load operation, offering insights into how decentralized systems adapt to dynamic market conditions and promote localized energy resilience. This study aligns with SDGs 7 and 13 by linking technical reliability with climate-adaptive infrastructure and localized investment strategies.

The concepts of digitalization, data-driven innovation, and knowledge integration are further emphasized by Song [82], who examines predictive modeling in energy storage innovation. The study identifies digital capabilities as key to bridging the gap between R&D and market application, positioning digital transformation as a foundational enabler of SETs. This aligns with SDG 4 (quality education) by emphasizing the need for knowledge systems that translate into innovation outputs and with SDG 7 by facilitating more efficient energy transition pathways.

Together, these studies demonstrate that technological innovation in SETs cannot be separated from its systemic conditions. Boujelbene et al. [12] and da Silva et al. [14] provide context-specific technological insights; Wicki and Hansen [57] and Liu and Liang [80] address system-wide and geopolitical inequalities; Weerakoon and Assadi [81] examine decentralization's technoeconomic feasibility; and Song [77] highlights digital transformation as a core accelerator. This body of work reinforces that SETs are not linear technological upgrades but require synchronized efforts across markets, institutions, and communities to ensure environmental resilience, financial accessibility, and inclusive progress.

Theme 5: Entrepreneurial Approach, Access, and Technology-Driven Business Models for Energy Inclusion (Purple)

Entrepreneurship plays a catalytic role in advancing sustainable energy transitions (SEEs) by linking innovation with equity, local agency with systemic planning, and business models with public value creation. Across diverse geographical and socioeconomic contexts, energy entrepreneurs operate within hybrid ecosystems that combine technology, finance, policy, and community engagement. These entrepreneurial pathways are vital for shaping decentralized access, inclusive economic mechanisms, and adaptive energy infrastructure—advancing SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation, and Infrastructure), SDG 10 (Reduced Inequalities), and SDG 13 (Climate Action).

A recurring theme is the centrality of inclusive financial mechanisms. Gatto [21] demonstrated that renewable energy microfinance initiatives in the Global South empower women to access solar energy technologies, highlighting a gendered pathway to energy equity. Microloans act as tools for inclusion and decentralization, yet their impact is contingent on broader institutional integration with national energy strategies. This highlights a tension between localized empowerment and systemic scalability, revealing the importance of institutional support structures.

This need for system-level alignment is also evident in Kolk and van's [22] analysis of public–public-public-private-partnerships (PPPs) in renewable energy development. Their research underscores that entrepreneurial business models are more effective when embedded in collaborative networks involving NGOs, governments, and private actors. These hybrid partnerships facilitate risk-sharing and service delivery in emerging markets, aligning entrepreneurial action with infrastructure development and co-investment supporting SDG 17 alongside SDG 7 and SDG 9.

When viewed through a macro institutional lens, entrepreneurship becomes a reflection of national capabilities. Karimi et al. [4] reported that renewable energy entrepreneurship flourishes in environments with structured commercial, policy, and knowledge infrastructures. Using a national innovation systems perspective, they argue that entrepreneurship is not merely an individual opportunity but a system-level mechanism for industrial transformation. This systemic framing reinforces the idea that entrepreneurial ecosystems must be supported by coordinated policy and institutional frameworks to contribute meaningfully to industry development (SDG 9).

At the urban level, Tomor [23] introduces the concept of "citipreneurs," which are civic entrepreneurs embedded in smart city governance. These actors facilitate the democratization of energy by aligning local priorities with innovation in infrastructure and governance. Their work reflects the interplay between local governance, sustainability, and urban resilience, aligning with SDG 11. Unlike microfinance or national-level systems, this urban civic lens highlights the role of citizen-led innovation in shaping energy access pathways within high-density urban contexts.

While many studies focus on social and institutional enablers, Valsan et al. [24] shift their attention to technological infrastructures. The AII-MICET framework leverages blockchain and AI for decentralized energy trading, enhancing peer-to-peer markets even in off-grid and rural regions. By enabling decentralized digital platforms, their approach supports carbon mitigation through sustainable grid integration (SDG 13) and energy access expansion (SDG 7). The emphasis on digital infrastructure also contributes to reducing the digital divide, pointing toward inclusive technological futures.

Technological entrepreneurship is also examined by Nejabat and Geenhuizen [25], who focus on university-based spin-offs. Their study identified venture capital access, market readiness, and regulatory compliance as key barriers to commercialization. They argue that ecosystem-wide collaboration is essential for the success of these ventures, linking entrepreneurial energy innovations with SDG 8 (Decent Work and Economic Growth) and SDG 9. Their findings complement the digital innovation and systemic support themes observed across other studies.

Collectively, these studies illustrate that entrepreneurship for sustainable energy is not a monolithic process but rather a dynamic, context-dependent practice. Gatto [21] and Kolk and van [22] emphasize financial inclusion and hybrid models; Karimi et al. [4] and Tomor [23] focus on institutional and urban ecosystems; Valsan et al. [24] and Nejabat and Geenhuizen [26] highlight high-technology pathways and commercialization challenges. The connecting thread is the role of business models not as static templates but as adaptive frameworks shaped by local, national, and global dynamics.

The entrepreneurial strategies that support sustainable energy must therefore be flexible, multisectoral, and SDG-aligned. Whether through microfinance in rural areas or blockchain in decentralized grids, the common denominator is the pursuit of integrated solutions that combine access, innovation, inclusion, and resilience.

From the analysis, the identified the major components and the relevant SDGs with themes were identified, which are presented in Table 2.

Table 2. Major Components of SEE Themes and their alignment with SDGs

Theme	Key Components	Mapped SDGs
Institutional Entrepreneurship and Governance in Sustainable Energy Transitions	Multiscalar governance (urban, regional, national, rural)	1 NO POVERTY; 7 AFFORDABLE AND CLEAN ENERGY; 8 DECENT WORK AND ECONOMIC GROWTH; 11 SUSTAINABLE CITIES AND COMMUNITIES; 13 CLIMATE ACTION; 17 PARTNERSHIPS FOR THE GOALS
	Policy-based entrepreneurship & institutional flexibility	
	Formal/informal coordination and legitimacy	
Externalities and Resilience in Sustainable Energy Systems	Socio-behavioral adaptability to climate disruptions	7 AFFORDABLE AND CLEAN ENERGY; 8 DECENT WORK AND ECONOMIC GROWTH; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 13 CLIMATE ACTION; 15 LIFE ON LAND
	Structural and technological readiness for resilience	
	Institutional planning for externalities	
Gender, Women's Entrepreneurship, Stakeholder Inclusion, and Sustainable Energy Access	Women-led entrepreneurship & gender-inclusive models	1 NO POVERTY; 5 GENDER EQUALITY; 7 AFFORDABLE AND CLEAN ENERGY; 8 DECENT WORK AND ECONOMIC GROWTH; 10 REDUCED INEQUALITIES; 11 SUSTAINABLE CITIES AND COMMUNITIES
	Stakeholder collaboration & participatory governance	
	Community energy democracy & empowerment	
Innovations and Advancements in Sustainable Energy Technologies (SETs)	Renewable tech innovation (e.g., PEM, hydrogen)	4 QUALITY EDUCATION; 7 AFFORDABLE AND CLEAN ENERGY; 10 REDUCED INEQUALITIES; 13 CLIMATE ACTION; 17 PARTNERSHIPS FOR THE GOALS
	TIS and system-level coordination	
	Digitalization & decentralized energy models	
Entrepreneurial	Inclusive finance	

Approach, Access, and Technology-Driven Business Models for Energy Inclusion	(microfinance, PPPs)	7 AFFORDABLE AND CLEAN ENERGY; 8 DECENT WORK AND ECONOMIC GROWTH; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 10 REDUCED INEQUALITIES; 13 CLIMATE ACTION
	Urban/rural entrepreneurship & digital tools	
	Commercialization and ecosystem alignment	

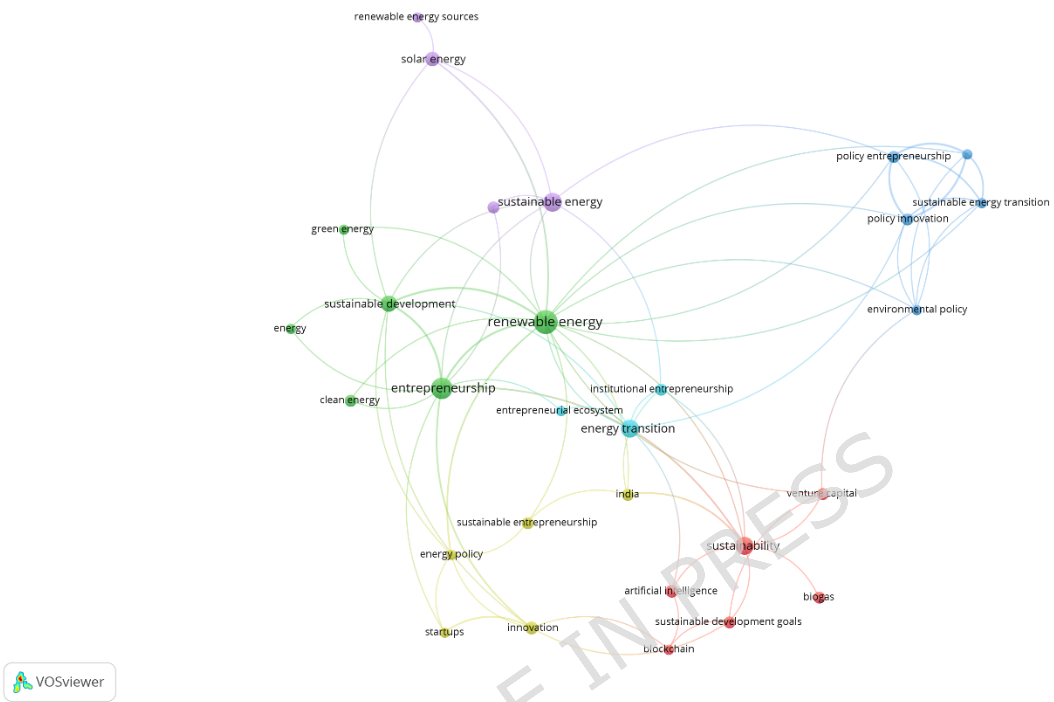

Figure 4. Thematic clusters

The cluster analysis reveals five dimensions such as governance, resilience, gender and stakeholder inclusion, technological innovation, and entrepreneurial/business models. These are not connected in the studies on SEE. The studies have one characteristic in a study, and there is no connection with the institutional level characteristics to technological solutions, or linking gender-inclusive practices to innovation or resilience mechanisms. The social, technological, and market characteristics in a unified framework of SEE are also missing. This shows a gap where SEE characteristics are analysed independently rather than as interlinked attributes of sustainable energy systems.

3.4. Methods

The methods adopted in the SEE research are examined here. The summary of approaches and the focus are also exhibited in Table 3.

Qualitative and case study approaches.

Qualitative studies follow an exploratory approach. Gning and Muchapondwa [26] followed multilevel participatory research through household interviews in 6 regions. Argade et al. [83] reviewed literature and case studies to identify opportunities in the context of Indian sustainable energy entrepreneurs and ethical fashion sectors by integrating National Business Systems (NBS) theory and conventional entrepreneurship frameworks. The case studies and interviews are integrated through an empirical observation by Gasbarro et al. [53] to reveal the engagement levels of sustainable entrepreneurs and public stakeholders.

Mixed-Method Approaches

The research method approach adopted in SEE research involves the integration of quantitative and qualitative lenses. The bibliometric analysis, qualitative synthesis through the analysis of 30 articles, and the integration of expert interviews from the 16 prominent experts from the European energy sector by Chatzinikolaou & Vlados [8], with an analysis of case studies of 89 business examples, revealed an understanding of changes in the policy. Nepal et al. [17] used a literature review and technical analysis in the context of blockchain-based smart energy systems, showing operational and transactional issues through the assessment of technical and review implementation aspects.

Quantitative studies

Karimi et al. [4] adopted panel data evaluation in 23 nations on the role of entrepreneurship. Liu and Liang [80] examine technology adoption and innovation in sustainability and adopt a quantitative approach through the cross-sectionally augmented autoregressive distributed lag (CS-ARDL) model. Similarly, decision tree analysis is used to compare the results with those of logistic regression, K-nearest neighbors, support vector machine, and naïve Bayes classifiers by Fadoul et al. [84] in terms of the feasibility of solar and wind solutions in East Africa, and data over eight years are used to identify seasonal variations and confirm the accessibility of renewable sources.

Analytical and Modeling Techniques

The other specialty of the documents found in this field is the adoption of analytical tools such as Interpretive Structural Modeling (ISM) and Decision-Making Trial and Evaluation Laboratory (DEMATEL) to identify and interpret relationships between barriers and challenges in the biofuel and renewable energy markets [80]. This shows the scope of energy in multidisciplinary disciplines such as engineering, science, and technology. The technology adoption phases are examined through the analysis of markets and the mapping of diffusion in the Indian SET context. This method follows simulations and mathematical models and lacks human interactions. Boujelbene et al. [12] examined the PEM fuel cell aspects through mathematical simulation models in computational modeling. Weerakoon & Assadi [81] adopted the generalized TEA framework and used the MCDM-TOPSIS ranking technique for the technological economic assessment of micro gas turbines.

Conceptual studies

Theoretical idea-based frameworks have been adopted in studies without any empirical examination. Valsan et al. [24] examined AI-blockchain contexts for future research experimental validation through conceptual analysis. Similarly, Eitan & Fischhendler [85] framed the conceptual frameworks of pitching to regulators through a literature review synthesis. Sun [86] integrated theory with machine learning and revealed a contextual and simulation-based analysis of green innovation and carbon. Conceptual research and bibliometric research are also adopted in this domain. Chatzinikolaou & Vlados [8] conducted a bibliometric analysis to synthesize the literature to discuss the research trends and merged it with qualitative and expert interviews on the emergence of sustainable energy policy.

Table 3. Overview of Research Methods used in SEE

Method	**Approach / Technique**	**Focus**	**Examples**
Qualitative	Case studies, interviews, and literature review	sustainable entrepreneurship, ethics, and stakeholder engagement	[26], [83]

Mixed-Method	Combines quantitative & qualitative, expert interviews	Policy changes and technical issues in smart energy systems	[8], [17]
Quantitative	Data analysis, models, and statistical techniques	Entrepreneurship, technology adoption, and renewable energy feasibility	[4], [87]
Analytical/Modeling	Simulations, ISM, DEMATEL, MCDM-TOPSIS	Technological, economic, and structural factors in energy systems	[87], [12]
Conceptual	Theory-based, no empirical data	Theoretical models and explore future research directions in sustainable energy	[19], [86]

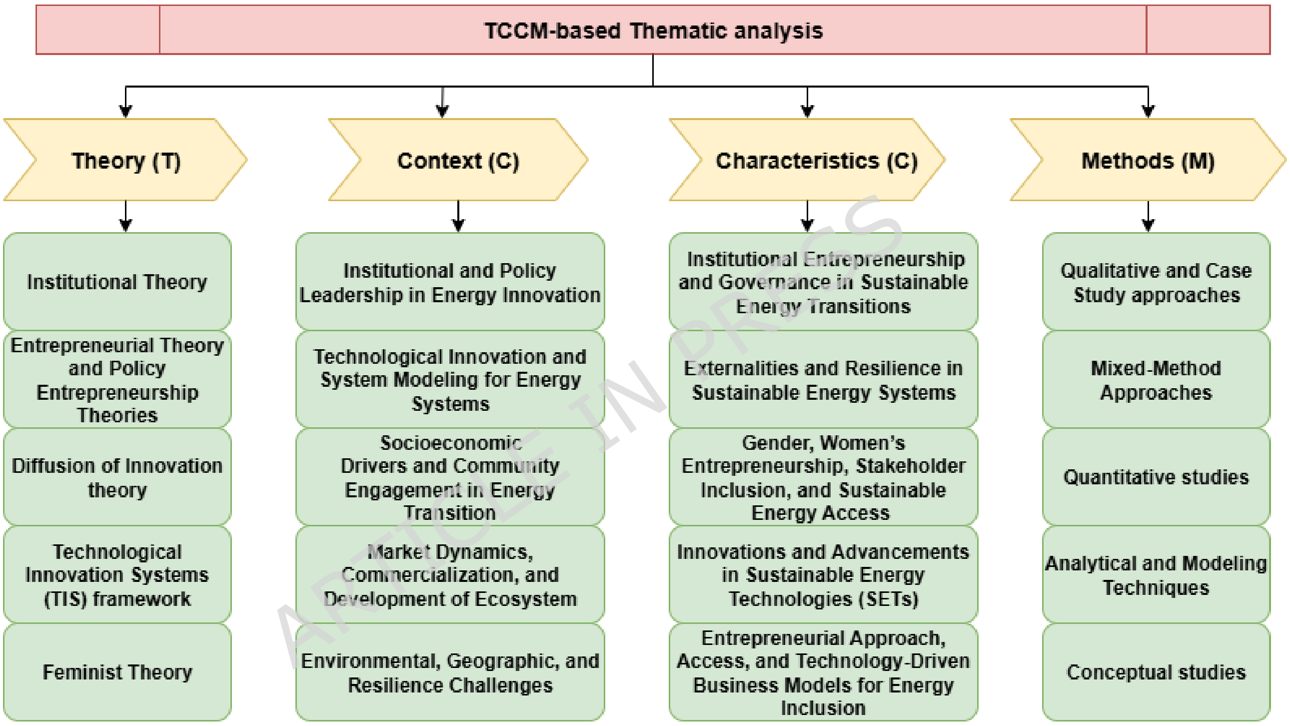

Figure 5. TCCM synthesis of SEE

The application of qualitative, mixed-method, quantitative, analytical, and conceptual approaches to the review is seen in the SEE research. However, these also highlight methodological gaps. The majority of research focuses on qualitative case studies or conceptual frameworks, and lacks the longitudinal research, experimental or quasi-experimental designs, and analysis based on large-scale quantitative datasets. The approaches on the cross-country comparative examination, simulation modeling, machine-learning-based evaluations, and mixed-method triangulation are also very limited. This limited methodological focus limits empirical precision, generalizability, and the validity of findings in SEE studies.

4. Discussion

This study revealed five major themes in SEE related to institutional support, externalities and resilience, gender inclusion, technological innovation, and inclusive business models. SEEs contribute to energy transitions by creating decentralized solutions, developing social inclusion, and promoting policy and digital platforms (RQ1). The key enablers of SEE include supportive policy frameworks, financial access, community engagement and participation, and technology adoption, whereas barriers include institutional support, gender differences, market readiness constraints, scaling of technologies or business models, and regulatory issues (RQ2). The synthesis with TCCM provides practical and theoretical directions for future SEE research by highlighting gaps in institutional theory integration, resilience planning, inclusive entrepreneurship, and technology adoption through the lens of antecedents, strategic decisions, and impacts of SEE linked with SDGs (RQ3).

The research showing an integrated examination of SEE by a scientist synthesizes combines lenses of governance, technological innovation, entrepreneurial action, social inclusion, and resilience. The results indicate that the functioning or operation of the SEE in multiple levels, like institutional, social, and technological, and that the existing body of knowledge analyzes these dimensions independently and lacks an integrated approach. The community-based financing, business model development by meeting local needs, alternative options such as microfinance, and PPPs identified in this study link with the examination of Solangi & Magazzino [10] on renewable energy adoption, which is influenced by strategies that cover the financial policy perspective, comprising both enablers and risks. Karimi et al. [4] used an adopted system-GMM panel data approach to examine 11 subindices of entrepreneurship comprising commercial infrastructure, R&D, internal market dynamics, etc., impacting RE production in 23 developed nations. This work focuses on macro- and developed-country aspects. However, our research connects entrepreneurial action and challenges and enablers at the global level, along with social inclusion and gender lenses. This bottom-up entrepreneurial focus in this research, which covers gender inclusion, resilience, and technology platforms, adds to macrolevel observations.

Institutional and stakeholder perspectives emerge as key enablers of SEE. Governance structures, policy frameworks, and participatory entrepreneurship ensure inclusivity and long-term impact, complementing Zaghdoud's [9] work on energy efficiency advantages and technological development in Tunisia. Effective SEE requires local policy alignment, robust governance ecosystems, and integration with accounting and reporting frameworks, echoing the urgency highlighted by Di Vaio et al. [2] for zero-carbon transitions. However, these technical-focused studies, such as those on solar energy storage in Western Australia, often overlook social, political, and environmental barriers. This study extends that the technological and infrastructural focus is not only enough, but there are challenges prevailing in the technical resilience, social, political, and environmental system-levels. Likewise, their study also further adds to the findings of Baquero & Monsalve [11] highlight social entrepreneurship in hydrogen economy transitions. This view is integrated in this research by combining gender, stakeholder inclusion, and SDG alignment in the context of SEE for the move toward more decentralized sustainable energy solutions.

AI and Energy 4.0 are discussed in the literature, which shows that technology is important in the sustainable energy transition. For example, Khalid [88] shows that AI and digital transition through Energy 4.0 open innovations in the sustainable energy sector by recognizing that the technology is a strategic enabler. This broader examination is further contributed to by grassroots-level exploration from the SEE perspective by this research, which reveals that the importance of technologies and their effective reach is necessary for marginalized populations and adapted socially, and different governance settings for ensuring energy access and inclusivity.

The highlighting of the isolation and lack of integration in the SEE research is clear here. The prior research explored the theoretical perspectives like Institutional Theory [48], Entrepreneurship and Policy Entrepreneurship theories [8,60], Diffusion of Innovation [56], Technological Innovation Systems (TIS) [3,57], and Feminist Theory [21,52]. These frameworks are largely adopted independently. The link among these in energy transitions through a sustainable energy entrepreneurship lens is not at all revealed in the current body of knowledge. Hence, SEE literature lacks a combined or integrated model on the multilevel interactions among institutional frameworks, entrepreneurial agency, technology energy systems, entrepreneurial agency, and gender lens-based social dynamics. The lack of hybrid theoretical models needs to be filled and requires examining and revealing how to accelerate innovations, ensure social inclusion, complexities, institutional and social dynamics, including cultural dimensions, and entrepreneurial dimensions of the SEE.

There are also methodological gaps in SEE research. The examination of the entrepreneurial models, technology innovation energy system, governance, social inclusion, gender perspectives, resilience, etc, is revealing the coordination at the multi-level, and the institutional entrepreneurial collaboration. Governance examination focusing on institutional entrepreneurship and multilevel coordination [54,67]; resilience dimension covers climate risk and adaptive capacity [66,70]; gender lens highlights women's entrepreneurship and inclusion [26,59]; technological innovation research examines hydrogen systems, digital tools, and energy storage [12,57]; and entrepreneurial model research examines finance, PPPs, and commercialization [21,22]. However, these do not integrate these dimensions and reveal cross-dimensional domain dynamics, especially on the influence of the gender dynamics in the entrepreneurial scaling in the sustainable energy sector, and how governance is impacting this, along with technological resilience. This study identified this and calls for further research.

Likewise, the methodological gaps were also highlighted in this research. The existing large focus on the SEE research is largely explored through qualitative and conceptual analysis, providing the contextual understanding, but lacks the causal or comparative insights [26,53,83]. In addition to this, the quantitative approach focusing on macro-focused [4,80,79] and the lack of tools like ISM, DEMATEL, and simulation analysis applications are mostly found in socially or institutionally oriented contexts. This study further adds to the existing literature that there is less Longitudinal examination, cross-country comparison, and integrated mixed-method designs, which leads to an inadequate understanding of the SEE evolution in the institutional, technological, gender, and community contexts. Addressing these gaps requires methodological diversification to reveal the interactions among these dimensions aligned with SDGs.

Another contribution of this study is the proposal of an integrated conceptual model for SEE. This integrated conceptual mechanism synthesizes the TCCM on how SEEs emerge from multi-level dimensions identified in this study. Institutional structures, including policy support, regulatory consistency, and governance capacity, drive or constrain the environment that influences entrepreneurs' ability to access and mobilize resources, legitimacy, and scale sustainable energy solutions. These institutional conditions directly influence entrepreneurial agency in opportunity recognition, strategic decisions, and adaptive behaviours according to market and policy dynamics. Entrepreneurial actions lead, technological adoption, where innovation diffusion mechanisms and Technological Innovation System (TIS) functions, such as collaboration, knowledge development, network building, resource access, and market formation, determine the viability and diffusion of energy technologies. Among these interactions, gender and stakeholder inclusion act as social dynamics that affect participation, accessibility, and equity in SEE processes, relating to differences in power, roles, and opportunity distribution. Externalities and resilience factors like policy uncertainty, climate risks, market dynamics, and infrastructure limitations influence how effectively SEEs can operate within institutional and technological systems.

Together, these interconnected elements show that SEE does not evolve from any single domain; rather, it develops through the combined influence of institutional governance, entrepreneurial agency, technology-system dynamics, social inclusion, and resilience-building mechanisms. This integrated interpretation aligns with the study's findings that SEE research has previously treated these domains independently, and demonstrates why a holistic, multi-level perspective is essential for understanding and strengthening sustainable energy entrepreneurship globally.

Hence, this study is an extension of the current SEE research by providing an SDG-aligned synthesis of SEE research. The identification of the theoretical, conceptual, structural, and methodological gaps required for hybrid theoretical frameworks, cross-context differences, and mixed-method or longitudinal designs-based research. Future research is required, and there is a need for extending knowledge on SEE research by filling these gaps, focusing on the development of SEEs by inclusive innovation, and resilient, scalable, sustainable energy solutions. This more comprehensive theoretical examination highlights the gaps and calls for future research and practical intervention in the areas of energy access, local governance, resilience, and innovation, which are highly relevant in the present scenario in light of the sustainable energy transition and achieving the sustainability goals and targets. Along with this, the study also calls for further research opportunities to adopt mixed methods, longitudinal designs, etc, or a comprehensive understanding of SEE in institutional, technological contexts, etc, even though the study has the following limitations. This is a systematic literature review based only on peer-reviewed English-language article publications in Scopus and Web of Science, which excludes grey literature, conference proceedings, regional reports, and non-English papers. The synthesis through the TCCM approach provides structure, but it lacks empirical understanding through first-hand primary data analysis from the inputs SEEs or longitudinal evolution in SEEs. SDG mapping, conducted using SciVal and validated through manual checking, can extend the advanced quantitative analysis in the future through Bidirectional Encoder Representations from Transformers Topic Modeling (BERTopic modelling), etc.

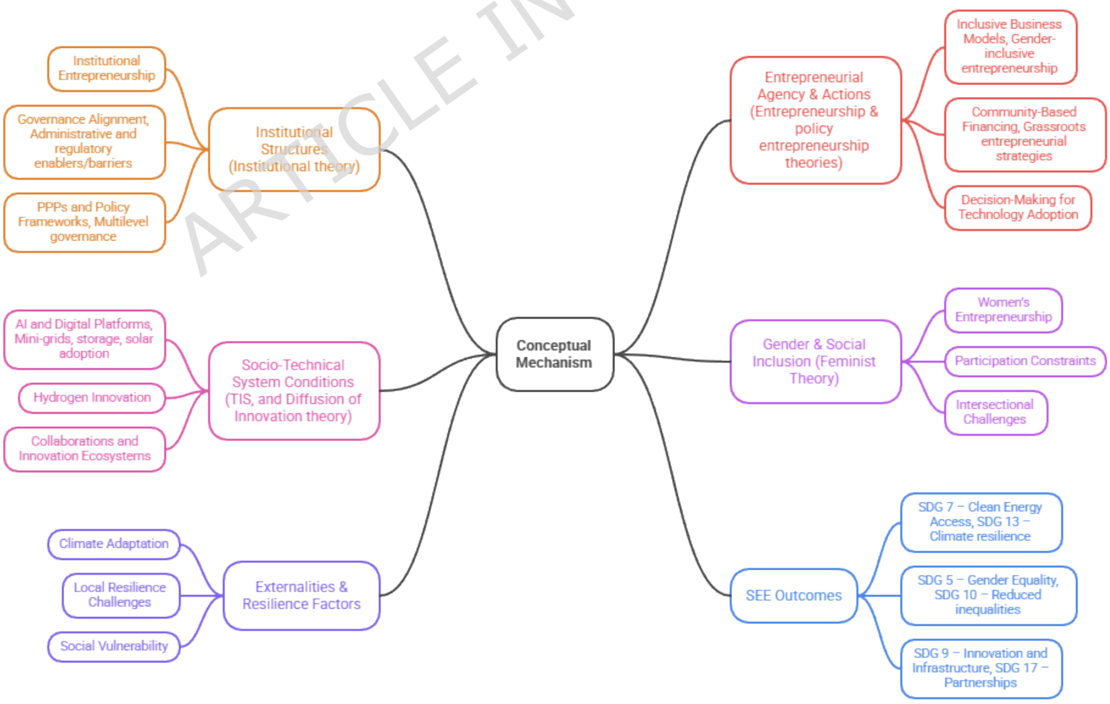

Figure 6. Integrated conceptual model-SEE

5. Implications

5.1. Implications for Theory

Five major themes are identified in the study of SEE through TCCM frameworks and the offering of future research avenues through the ADO, which contributes to the existing entrepreneurship and energy research literature. The institutional challenges highlighted in this research align with the enablers contributing to institutional theory by showing that SEEs' success is influenced by policy mechanisms, governance systems, and regulatory environments. Similarly, technology development and market-based support contribute to TIS frameworks by highlighting the importance of knowledge creation and legitimacy, and the system-based link leads to the diffusion of innovation. Gender and community participation in SEEs' success are aligned and contribute to stakeholder theory. The study covers the broader lens of SEE, combining different angles, such as policy, gender, community, resilience, technology, business models, and social environmental outcomes, which provides a multi-theoretical approach and contributes to innovation and social theories. This study not only validates the current theories but also contributes to entrepreneurship research by connecting with social inclusion, technology development, policy, and market dynamics in SEE, which can guide further research.

This study contributes SEE literature through developing an integrated framework integrating the core constructs from institutional theory (rules, norms, legitimacy), entrepreneurship and policy entrepreneurship theories (opportunity recognition, strategic decision-making, accessing & mobilizing resources, agency, creating new energy models), diffusion of innovation (relative advantage, complexity, compatibility, observability), TIS (knowledge development, resource mobilization, market formation, legitimation of innovations), and feminist theory (gender norms, resource inequalities, intersectional challenges). Prior research approached these constructs independently. By synthesizing them, this review shows that SEE outcomes emerge from the interaction of institutional constraints, entrepreneurial agency, system-level functions, community adoption dynamics, and gender-inclusive mechanisms. This integrated construct-based framing provides the first unified theoretical model explaining how SEEs create decentralized innovation, ensuring local resilience, inclusive energy access, and contribute to energy transitions, thereby extending existing theories rather than single-lens interpretations.

5.2. Implications for Policy

The findings call for more inclusive, supportive, and flexible policy frameworks for the promotion of SEEs. Institutional support is the major enabler, and governments and policymakers need to eliminate regulations related to red tape and the need to facilitate support for meeting national and global energy targets and developing local-level entrepreneurial initiatives. Financial incentives, regulations that attract more startups, and the encouragement of multistakeholder collaborations will develop the entrepreneurial ecosystem. The role of gender-inclusive entrepreneurship in mitigating gender disparities and community participation in clean energy access needs to be focused on by policymakers, especially through developing gender-inclusive policies and awareness of sustainable energy sources, and ensuring proper training. The offerings of funds, training initiatives, and leadership development for women and underprivileged regions need to be focused on. The resilience in the study shows that policymakers need to plan for climate change risks, market changes, and geopolitical issues. The development of decentralized business models and the enhancement of digital literacy will help SEEs and the development of infrastructure, and support policies encouraging peer-to-peer energy trading and microgrid-based innovations will also need to be focused on by both developing and developed countries. The policies need to change from a narrow focus on technologically based development to more entrepreneurial ecosystem development in the energy sector toward an agenda for SDG achievements through participatory, context-based, collaborative initiatives, which will cover SDG 7, SDG 5, and SDG 13.

5.3. Implications for Practice

This study offers practical insights for entrepreneurs, ecosystem accelerators, and clean energy innovators. Entrepreneurs should design inclusive business models that are resilient to externalities and benefit marginalized populations, including women and rural communities. SEEs and startups that integrate gender equity and community collaboration will have high success possibilities, scaling, and sustainability. Practitioners must also recognize that the importance of developing strategic relationships with policymakers, NGOs, and financing institutions can improve legitimacy and access. The findings highlight the need for digital platforms and decentralized energy systems such as AI-powered grids and blockchain-based energy trading, which enhance access and transparency. Capacity-building initiatives, including technical training, financial literacy, and mentoring, support early-stage and local entrepreneurs in emerging markets. Environmental resilience is the most important focus for which practitioners must ensure sustainability, risk evaluation, and adaptability in sustainable energy planning. Entrepreneurs should link their operations with the SDGs. Practitioners should develop a supportive ecosystem, and SEEs need to build community-based, innovation-enabled solutions that effectively contribute to equitable and sustainable energy transitions.

6. Future Research Directions—the ADO Framework

The Antecedents–Decisions–Outcomes (ADO) framework [26, 35] is a theory-building approach that helps in the structured identification of the drivers (antecedents), choices (decisions), and consequences (outcomes/impact) of a particular case. The TCCM analysis provides the analytical foundation from which the ADO is derived. Theory and Context identify the structural and environmental level antecedents, like institutional conditions, technological readiness, and social inclusion factors. Characteristics highlight how entrepreneurs respond to these antecedents, contributing to informing the key decisions related to technology adoption, business models, governance, and scaling strategies. Methodology synthesizes the outcomes, including energy access improvements, innovation diffusion, community empowerment, and resilience. This creates the synthesis through TCCM into a more structured ADO framework. Here, the Theory and Context results reveal the core antecedent representing the systemic conditions SEEs must direct. The Characteristics, like community co-creation models, inclusive business, resilience strategies, and decentralized technology choices, represent the decisions entrepreneurs make in response to these antecedents. The methodology results identify measurable outcomes like expanded energy access, adaptation capacity improvements, enhanced community engagement, and the diffusion of clean-energy innovations. The ADO is aligned with the SDGs and supports theory development, which is helpful for further research in this emerging and multidisciplinary field (Table 4).

6.1. Antecedents: Institutional dynamics, Gender Inclusion & Technological preparedness

The results indicate that institutional conditions, such as policy, regulatory support and assistance, economic or financial incentives, gender inclusion, and digital readiness, are the key accelerators for enhancing SEEs. These are the major drivers or antecedents that promote startup success and the further scale-up of these ventures. While looking into each driver, institutional support through flexibility in regulations, formulating policies for attracting new startups in the sustainable energy sector, providing more subsidies, and ensuring the formation of decentralized governance will create a favorable environment for the SEE ecosystem.

Another important antecedent is gender equity, which is achieved through gender inclusion-based strategies that support women entrepreneurs and ensure affordable and equitable energy access in rural and other disadvantaged areas. Technological readiness and digital preparedness involve the integration of modern technologies such as blockchain and artificial intelligence (AI)-powered solutions for decentralized energy system models, including microgrids. These antecedents are linked to different SDGs, such as SDG 7, through a focus on equitable clean energy access; SDG 5, through strategies for inclusive women's entrepreneurship development; SDG 9, through the promotion of innovation and digital literacy and technology adoption; and SDG 10, through the participation and coverage of the marginalized population and the reduction of differences in sustainable energy system development, which benefits all without inequalities.

Future research can focus on institutional dynamics, such as policy roles and governance, which influence SEEs' feasibility and development and align with institutional theory. Gender and inclusivity in SEEs connect feminist theory, technology adoption, availability in SEEs' operations related to the TIS, tangible and intangible resources such as finance, and technology capital under the resource-based view (RBV), and the importance of self-efficacy and expectations, such as gender perceptions, which affect entrepreneurs and women SEEs, reflects social cognitive theory. Based on these antecedents, the following future research questions and propositions are framed.

Future Research Questions:

- FR1: How do institutional and cultural factors influence SEE development across different regions?
- FR2: To what extent do entrepreneurial self-efficacy and access to resources influence SEE performance and scale-up?
- FR3: What is the role of gender policies in promoting women's SEEs in light of Sustainable Development Goals?

6.2. Decisions: business model choices, technology adoption, and strategic partnerships

The antecedents leading to decision-making related to the business model, adoption of technology, and strategic stakeholder collaboration. The study revealed that inclusive business models are required in SEEs, with a focus on prioritizing affordability and social equity. The decentralized energy technologies relating to the microgrids, blockchain, and AI for creating community-based, locally based energy trading and solution decisions are important. Likewise, collaboration and strategic partnerships among key stakeholders, NGOs, and policymakers constitute another strategic decision. The decisions concerning climate change mitigation focus more on renewable energy sources and the development of SETs, leading to a reduction in carbon emissions, which aligns with SDG 13. Similarly, innovations and the community-oriented approach meet the energy demands of local populations and extend their solutions to rural and other underprivileged areas, contributing to SDG 7, and collaboration and partnerships, i.e., multistakeholder involvement decisions, contribute to sustainable energy transitions, supporting SDG 17.

Future Research Questions:

- FR4: How does SEE assess and make decisions on whether to select centralized and decentralized models in an uncertain environment? What are the factors influencing their decisions?
- FR5: What is the relationship between entrepreneurial orientation and perceived control of inclusive business models?
- FR6: What are the impacts of the adoption of inclusive innovative business models on enhancing community resilience and scalability, and are there any challenges to this?

6.3. Outcomes: Energy Access, Social Inclusion & Climate Resilience

The outcomes of decisions include energy access improvement, social inclusion, financial development, and climate resilience. These consequences of decisions align with institutional readiness and community requirements. Inclusive SEE models lead to energy access, contributing to the creation of employment, eliminating gender gaps, and enhancing local access. SEEs prioritize resilience and sustainable design, promoting communities to achieve climate change mitigation and sustainability targets. These impacts are linked with SDG 7 through energy access, SDG 8 by opening new employment opportunities and contributing to the development of enterprises, leading to economic growth by promoting the energy sector on a sustainable path, SDG 10 by fostering inclusive access models, and SDG 13 in line with a reduction in carbon emissions and climate change.

Future research can be conducted through the following theoretical lenses, such as stakeholder theory, by focusing on how SEE creates value for stakeholders other than profit, sustainability transitions theoretical aspects through the innovation of enterprises in a niche-focused strategy, and contributes to the overall growth of the sustainable energy sector in developing and developed countries, which presents a niche innovation impact on SEEs to the sustainable energy ecosystem through influencing the relationships among multilevel factors, resilience frameworks through adaptation and communities toward SEE innovations even in the presence of socioeconomic changes.

Future Research Questions:

- RQ7: What stakeholder outcomes (social, environmental, economic) are from the integration of inclusive SEE models in low-income and climate-change contexts?
- RQ8: How do SEE models contribute to long-term resilience in energy-underserved areas, especially in the context of developing regions?
- RQ9: What are how SEEs create value for stakeholders and contribute to sustainable energy transitions?

Table 4. ADO Framework-based Research Agenda

ADO Elements	Key themes	SDGs Covered
Antecedents	Institutional support, gender inclusion, tech readiness	5 GENDER EQUALITY; 7 AFFORDABLE AND CLEAN ENERGY; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 10 REDUCED INEQUALITIES
Decisions	Business model design, decentralized tech, strategic alliances	7 AFFORDABLE AND CLEAN ENERGY; 13 CLIMATE ACTION; 17 PARTNERSHIPS FOR THE GOALS
Outcomes	Energy access, inclusion, economic uplift, and climate resilience	7 AFFORDABLE AND CLEAN ENERGY; 8 DECENT WORK AND ECONOMIC GROWTH; 10 REDUCED INEQUALITIES; 13 CLIMATE ACTION

7. Conclusion

The research explores SEE through a systematic and structured thematic examination. This TCCM-ADO framework provides an in-depth, comprehensive understanding of how SEEs are innovating, ensuring energy access, resilience, and a policy and regulatory landscape that is leading to a sustainable energy transition. The novelty of this study, in terms of its multidimensional nature, lies in its distinctiveness from other studies focused on micro-observations, such as technology, mate treatment, or policy-related examinations. While comparing to previous research works, this study combines the isolated areas into a single integrated framework synthesis on the technological adoption, policy lens, decentralized energy system representing social inclusion, etc Hence, this is the first multidimensional synthesis that links institutional, technological, social, and market factors to the mechanisms of sustainable energy transitions.

The major findings highlight that five key themes emerged in the following domains: (1) institutional frameworks and governance, (2) externalities and resilience, (3) gender inclusion and stakeholder participation, (4) innovation in sustainable energy technologies, and (5) inclusive business models for energy access. The study shows that the contribution of SEE to systemic change is through community development, policies, and decentralized innovations. A key scientific contribution of this study is the conceptualization of SEE as a multi-level change agent, rather than revealing a technology or business-oriented player. The findings highlight that SEE influences sustainable transitions by developing community-oriented innovation ecosystems, focusing on building advanced decentralized and adaptive technological energy system solutions for generating inclusive market structures for underserved communities, etc.

The major findings highlight that five key themes emerged in the following domains: (1) institutional frameworks and governance, (2) externalities and resilience, (3) gender inclusion and stakeholder participation, (4) innovation in sustainable energy technologies, and (5) inclusive business models for energy access. The study shows that the contribution of SEE to systemic change is through community development, policies, and decentralized innovations. By aligning these insights with the SDG agenda, this directly addresses the identified literature gap that previous reviews approach these domains independently, lacking an integrated explanation of how SEEs drive systemic change across levels (micro-meso-macro).

This approach is integrated with ADO frameworks to offer potential future research avenues. This is aligned with the SDGs such as SDG 7, which involves the development of inclusive and decentralized energy systems; SDG 5, which highlights that women's entrepreneurship is a sustainable energy sector; SDG 9, which involves technology-based solutions; SDG 10, which involves ensuring energy to marginalized communities; SDG 13, which involves the development of adaptive, resilient energy models; and SDG 17, which involves encouraging strategic partnerships and cross-sectoral cooperation. The major actionable recommendation of this research is the call for energy access by SEE in underprivileged populations, with policymakers due to SEE being key catalysts for sustainable energy transitions. The future of clean energy solutions is not technology-oriented; it is more inclusive, resilient, and socially and economically innovative through promoting SEEs.

Declarations

Funding statement: No funding support was received for the study

Competing interests: The authors declare that they have no competing interests. All authors reviewed the manuscript. There is no issue regarding consent to publish.

Data availability: All the data are available in the manuscript.

Ethics, Consent to Participate, and Consent to Publish declarations: Not applicable.

Clinical Trial Number: Not applicable

Author contributions statement: A.T.A. & R.R-Writing-Original draft. S.M. & R.R-

Supervision, Review & Editing. A.T.A and R.R- Methodology.

Acknowledgment: The authors are thankful for the anonymous reviewers.

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