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From Drivers to Scenario Logic: An Interpretive Meta-Synthesis of Selected Studies on Renewable Energy Development

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A B S T R A C T

In scenario planning for renewable energy development, identifying drivers alone is insufficient unless their links to future states, narratives, model assumptions, and implications for decision-making are explicitly clarified. This study aims to develop a traceable framework for transforming evidence from selected studies into scenario-design logic and for distinguishing among factors, uncertainties, deployment capacity, and outcomes. Using an interpretive meta-synthesis approach, nine selected studies published between 2020 and 2026 were examined. From the relevant sections of the sources, 49 meaning units were extracted and organized into 18 descriptive codes and six analytical themes. The assignment of meaning units to codes was documented, and thematic coverage was assessed through a leave-one-study-out analysis. The six themes were: problem framing and the contextualization of the future; actor agency and deployment capacity; transforming drivers into uncertain future states; consistency and translation between narratives and models; multidimensional outcomes and the boundaries of sustainability claims; and critical scrutiny, reflexivity, and learning. The analysis highlighted three key distinctions: technical capability versus organizational feasibility of use, factor influence versus future uncertainty, and technical improvement versus net developmental outcomes. Following the separate exclusion of each study, all themes retained at least one supporting meaning unit; however, three codes were dependent on a single study. For each scenario function, the proposed framework specifies an output and a control question so that the relationships among evidence, codes, themes, and design decisions can be reviewed and traced. The framework is conceptual, and its effectiveness for decision-making requires independent evaluation.

Keywords: *renewable energy, drivers, scenario planning, interpretive meta-synthesis, uncertainty*

1. Introduction

The transition toward renewable energy has moved from a largely technological agenda to a multidimensional transformation involving infrastructures, institutions, markets, organizations, users, regulatory systems, investment patterns, and social expectations. Renewable energy resources are central to decarbonization strategies because they can reduce dependence on fossil fuels, diversify energy supply, and support long-term environmental objectives; however, their deployment also introduces challenges related to variability, system integration, infrastructure requirements, investment, technological maturity, and governance (Ellabban et al., 2014). These challenges become more complex when renewable energy development is considered not as a single technological substitution process but as part of a broader socio-technical transition in which technological change interacts with organizational capacity, public participation, market design, and policy choices (Pregger et al., 2020; Weimer-Jehle et al., 2020). Accordingly, strategic planning in this field requires approaches capable of addressing multiple plausible futures rather than relying exclusively on deterministic projections or linear extrapolations.

Scenario planning has become one of the principal approaches for dealing with such complexity because it provides a structured way of examining alternative futures under conditions of uncertainty. Unlike conventional forecasting, which often seeks the most likely continuation of current trends, scenario approaches are designed to explore multiple pathways, including exploratory, normative, and anticipatory futures (Börjeson et al., 2006; Skea et al., 2021). Scenario planning can support strategic learning by helping decision-makers examine how different combinations of drivers, uncertainties, institutional conditions, and technological developments may alter future outcomes (Amer et al., 2013). Nevertheless, the value of a scenario exercise depends not merely on generating several narratives but on clarifying the analytical logic by which drivers are identified, transformed into future states, combined into internally coherent configurations, and interpreted in relation to decision-relevant outcomes.

A persistent methodological challenge concerns the treatment of drivers. In many scenario studies, economic, technological, political, social, regulatory, and environmental variables are identified as influential factors, yet influence alone does not establish that a factor should serve as a defining uncertainty or scenario axis. A driver may be highly influential but relatively stable, whereas a moderately influential factor may be deeply uncertain and therefore critical for differentiating alternative futures. The conceptual distinction between influence, uncertainty, and outcome is therefore essential for scenario design (Walker et al., 2003). Studies of local energy and flexibility markets, for example, demonstrate that drivers such as user participation, digital capability, regulation, and market organization can interact in ways that produce substantially different future configurations (Mirzaei Alavijeh et al., 2021). Similarly, Delphi-based work on renewable energy futures indicates that expected developments, preferred developments, policy measures, and stakeholder judgments should not automatically be collapsed into a single representation of the future (Rikkonen et al., 2021). These observations suggest that the analytical transition from a list of drivers to explicit alternative states requires greater methodological attention.

The problem becomes more pronounced when scenarios span different spatial and institutional scales. Energy transitions are shaped simultaneously by global climate commitments, national policy frameworks, regional infrastructure conditions, local institutional capacity, and organizational implementation processes. Linking scenarios across scales can therefore improve contextual coherence, but such linkage may also conceal assumptions when higher-level scenarios are treated as fixed backgrounds rather than contingent contexts (Zurek & Henrichs, 2007). Experience from integrated socio-technical energy scenarios shows that national, regional, and sectoral scenario layers may need to be explicitly connected so that assumptions made at one level are visible at another (Prehofer et al., 2021). This issue is especially relevant when renewable energy development is analyzed in specific countries or regions because global technological trajectories and national policy assumptions may constrain local scenarios without fully determining them.

Another important issue is the relationship between qualitative narratives and quantitative models. Energy scenario research frequently combines narrative storylines with simulation, optimization, system-dynamics, or other quantitative models. Such integration can strengthen analytical depth, but only if the translation between qualitative statements and quantitative parameters is transparent and reviewable (Prehofer et al., 2021). Narrative concepts such as “high adoption,” “strong participation,” or “rapid technological progress” may correspond to substantially different parameter values depending on the modeling framework and assumptions used. Methodological

studies have therefore emphasized that qualitative–quantitative integration is not a mechanical conversion process but a knowledge-integration activity requiring explicit rules, iterative feedback, and documentation of interpretive choices (Weimer-Jehle et al., 2020). Experiences from German energy-transition scenario building further indicate that socio-technical scenario development benefits from combining structured cross-impact approaches with explicit reflection on actor behavior, institutions, and technological constraints (Pregger et al., 2020).

Participatory approaches have also gained importance because energy transitions involve heterogeneous actors whose interests, capacities, and knowledge are not interchangeable. Participatory modeling can support the inclusion of stakeholder perspectives, improve legitimacy, and reveal implementation barriers that purely technical modeling may overlook (Campfens et al., 2025). However, the theoretical capability of a participatory method should not be assumed to be equivalent to its demonstrated effectiveness in practice. The quality of participation depends on who is included, how knowledge is elicited, how disagreements are handled, and how stakeholder input is incorporated into model structures or scenario narratives. This distinction is significant because participation may serve different functions, including consultation, co-design, validation, learning, or decision support, and these functions should be analytically separated rather than treated as equivalent.

The organizational capacity to use technology constitutes another underdeveloped dimension in many future-oriented energy studies. Technological availability does not necessarily imply effective deployment. Research on integrated urban planning and net-zero transitions indicates that organizations may face fragmented datasets, incompatible information systems, limited analytical skills, insufficient staffing, procurement constraints, and difficulties translating data into operational decisions (Mazumdar et al., 2023). Consequently, the existence of technical infrastructure should be distinguished from actual usability and institutional capacity. This distinction is especially relevant for digitalization and artificial intelligence, where advanced analytical systems may generate recommendations that organizations are unable or unwilling to implement. The deployment of AI in climate and energy systems is conditioned by data availability, computational infrastructure, institutional incentives, governance mechanisms, and human expertise (Kaack et al., 2022; Stern et al., 2025). Thus, scenario design should consider not only whether a technology exists but also whether relevant actors possess the authority, resources, skills, and motivation required to use it.

These considerations have become increasingly important as artificial intelligence is incorporated into discussions of renewable energy futures. AI may contribute to forecasting, demand management, grid optimization, maintenance, storage coordination, resource allocation, and integration of variable renewable generation, yet such benefits are conditional rather than automatic (Kaack et al., 2022). Broader assessments of AI and the climate transition emphasize that potential gains depend on adoption rates, energy-system context, implementation quality, and rebound effects, while indirect consequences may offset part of the expected benefit (Stern et al., 2025). Scenario-based analyses of AI in climate-responsive energy systems similarly demonstrate that future outcomes are shaped by interactions among technological capability, data infrastructure, investment, skills, governance, and institutional preparedness (Fathi & Mirsaeid Ghazi, 2026). For this reason, AI can be treated not merely as a technological driver but as a context-dependent socio-technical capability whose consequences vary according to deployment conditions.

The importance of context is also evident in sustainability assessment. Renewable energy technologies may perform differently depending on the baseline system, life-cycle boundary, geographic conditions, infrastructure assumptions, and indicators selected for evaluation. Prospective sustainability assessment therefore requires explicit attention to environmental, economic, and social dimensions and to the limits of the indicators used (Haase et al., 2022). A technological improvement within one subsystem should not automatically be interpreted as a net sustainability gain for the wider energy system. For example, increases in installed renewable capacity, renewable electricity generation, renewable share, avoided emissions, system flexibility, and social accessibility represent different outcomes and may not move in the same direction. The analytical boundary must therefore be explicit before scenario results are converted into claims about sustainability or development.

In parallel with model-based approaches, narrative and storytelling methods have received growing attention as mechanisms for making future energy pathways more understandable, experiential, and socially meaningful. Narrative approaches can expose assumptions concerning

everyday practices, household behavior, social expectations, and institutional change that may remain hidden in numerical models (Dahlgren et al., 2024). Storytelling methods can also reveal how alternative futures are framed as desirable, undesirable, plausible, or contested, thereby enriching the interpretive dimension of scenario research (Sol Cueva, 2025). Research on democratic and socially engaging energy transitions similarly emphasizes that narratives, expectations, and policy criteria influence how energy futures are understood and legitimized (Campos et al., 2024). Nevertheless, narrative richness alone does not guarantee analytical consistency, and scenario narratives require explicit links to drivers, assumptions, and evaluative criteria.

The expanding methodological diversity of energy-futures research creates a need for frameworks capable of comparing evidence across heterogeneous study designs. Selected studies may include expert elicitation, Delphi methods, participatory modeling, cross-impact analysis, qualitative interviews, sustainability assessment, literature reviews, and model-based estimation. Such heterogeneity limits the usefulness of conventional statistical aggregation and increases the relevance of interpretive synthesis. Critical interpretive synthesis was developed precisely to integrate diverse forms of evidence while remaining attentive to conceptual variation, methodological limitations, and the interpretive nature of knowledge construction (Dixon-Woods et al., 2006). Thematic synthesis provides another useful methodological foundation by distinguishing descriptive coding from the generation of higher-order analytical themes (Thomas & Harden, 2008). These approaches are particularly suitable when the research question concerns relationships among concepts rather than pooled effect sizes.

Methodological transparency remains critical in such syntheses. Qualitative evidence synthesis requires explicit reporting of how studies are identified, selected, appraised, coded, and interpreted. ENTREQ emphasizes transparency in reporting synthesis methods, including search, appraisal, synthesis procedures, and the development of findings (Tong et al., 2012). PRISMA likewise provides principles for transparent reporting of review procedures, even though not every interpretive synthesis constitutes a conventional systematic review (Page et al., 2021). In purposive qualitative synthesis, moreover, the logic of source selection should be based on informational relevance, conceptual diversity, and richness rather than solely on sample size or exhaustive database coverage (Ames et al., 2019). These principles are especially important when the analytical sample is intentionally selected to illuminate complementary dimensions of a complex problem.

A further challenge is distinguishing methodological robustness from apparent evidentiary density. Multiple publications may rely on overlapping projects, shared datasets, similar conceptual frameworks, or recurring methodological traditions. Repetition across publications therefore does not necessarily represent independent corroboration. Similarly, the persistence of an analytical theme after removal of one source does not prove its empirical validity; it only indicates that the theme remains represented within the available evidence base. Sensitivity analysis of code and theme coverage can nevertheless help identify components that depend heavily on individual studies and reveal where analytical conclusions are structurally fragile. This is particularly useful in interpretive meta-synthesis, where conceptual traceability may be more informative than numerical weighting.

The literature also demonstrates that energy scenarios differ in purpose. Some scenarios explore what could happen, some examine what should happen, and others investigate how a preferred future could be achieved (Börjeson et al., 2006; Skea et al., 2021). These purposes imply different assumptions, evaluative criteria, and standards of interpretation. A scenario intended to explore technological disruption should not be evaluated by the same logic as a normative decarbonization pathway. Similarly, a scenario designed to support organizational implementation requires greater attention to actor capabilities, data access, and institutional constraints than a global emissions pathway. Reviews of scenario planning have repeatedly shown that clarity about purpose, scope, actors, drivers, uncertainties, and outputs is fundamental to the usefulness of scenarios for strategic decision-making (Amer et al., 2013).

The development of renewable energy also increasingly depends on coordination among technological systems, policy institutions, communities, and markets. In Iran, for example, renewable energy futures are shaped by policy frameworks, investment conditions, infrastructure, technological access, and institutional capacity (Ghouchani et al., 2021). More recent scenario-oriented work has further highlighted the possible role of AI, data infrastructure, human capital, and financing in climate-responsive energy systems (Fathi & Mirsaeid Ghazi, 2026). However, studies from one national setting cannot be transferred mechanically to another, because deployment conditions, governance

structures, and market institutions vary substantially. This reinforces the need for a framework that distinguishes context-specific evidence from more general methodological propositions.

The same concern applies to emerging digital and intelligent energy systems. AI-supported forecasting, optimization, and decision support may improve technical performance, but their developmental value depends on whether organizational systems can absorb and use them effectively. The distinction between technical capability, institutional usability, and willingness to use is therefore crucial. An organization may possess advanced analytical tools but lack decision authority, trusted data, skilled personnel, or procedures for incorporating model outputs into operations. Conversely, motivated actors may lack access to the necessary infrastructure. By separating these dimensions, scenario analysis can more accurately represent the conditions under which technological potential becomes operational capacity.

Taken together, the literature suggests that a rigorous scenario framework for renewable energy development should address at least six interconnected issues: explicit problem framing and contextual boundaries; actor agency and deployment capacity; conversion of drivers into uncertain future states; consistency and translation between narratives and models; multidimensional impact assessment; and reflexive review of assumptions and evidence. These dimensions are present across the literature but are often treated separately in scenario studies, methodological reviews, participatory modeling, sustainability assessments, and technology-focused analyses (Campfens et al., 2025; Campos et al., 2024; Dahlgren et al., 2024; Haase et al., 2022). A synthesis that integrates these strands may therefore help clarify how evidence can be transformed into a traceable scenario-design logic.

Such integration is especially important because scenario planning is intended to support decision-making under uncertainty rather than merely produce descriptive future narratives. Its usefulness depends on whether decision-makers can trace how evidence was transformed into drivers, how drivers became alternative states, how states were combined into narratives, how narratives were translated into models, and how modeled outputs were interpreted within defined assessment boundaries. Without this traceability, scenario results may appear methodologically sophisticated while remaining difficult to audit, reproduce, or revise. A transparent framework can therefore support both analytical rigor and organizational learning by making assumptions, inferential steps, and decision points explicit.

Accordingly, the aim of this study is to develop a traceable interpretive meta-synthesis framework that transforms evidence from selected renewable-energy studies into scenario-design logic by distinguishing problem context, actor and deployment capacity, drivers and future uncertainties, narrative–model translation, multidimensional impacts, and reflexive learning.

2. Methods and Materials

Design and Rationale for Selecting Meta-Synthesis

The study was conducted using an interpretive meta-synthesis approach to selected studies. The subject of synthesis comprised published propositions concerning scenario design, deployment conditions, and impact assessment. The sources included expert-based studies, methodological analyses, reviews, and model-based estimates; therefore, comparison focused on the meaning of propositions and the boundaries of their applicability (Dixon-Woods et al., 2006). To organize the analysis, the distinction between descriptive coding and the generation of analytical themes proposed by Thomas and Harden was used (Thomas & Harden, 2008). This adaptation was limited to sections relevant to the research question and did not involve line-by-line coding of all texts. The analytical pathway proceeded from meaning units to descriptive codes and subsequently to analytical themes; no pooled effect size was calculated.

Source selection was purposive and did not seek comprehensive coverage of the energy-scenario literature. To enhance transparency in reporting source selection, critical appraisal, and the synthesis pathway, relevant dimensions of the ENTREQ and PRISMA guidelines were used. Their use was limited to reporting purposes and does not imply that a systematic review was conducted or that all items of these guidelines were fully followed (Page et al., 2021; Tong et al., 2012).

Source Identification and Inclusion Criteria

Source identification began with initial references relevant to the research problem and continued through title and digital identifier searches and consultation of publisher websites or academic repositories. Studies were selected on the basis of their relevance to the conceptual question and accessibility of textual evidence rather than comprehensive database coverage.

Inclusion in the coding set required three conditions: clear relevance to scenario construction or one of its associated links, such as deployment capacity and impact assessment; verification of bibliographic information; and access to relevant sections of the methods, findings, or discussion beyond the title and abstract. Differences in scale and methodology were considered in source selection in order to cover conceptual diversity. Studies limited to short-term forecasting of a single variable or equipment optimization were excluded when they did not provide propositions relevant to the synthesis question. Sources defining concepts and methodological guidelines were kept separate from the coding set.

In purposive sampling for qualitative synthesis, diversity of studies, information richness, and closeness of content to the purpose of the synthesis may serve as the basis for selection, and the rationale for this selection should be reported transparently (Ames et al., 2019). In the present set, the differing roles of the sources enabled comparison among scenario design, deployment, and impact assessment. This diversity, by itself, does not demonstrate sample adequacy. A stopping rule for source selection and a comparative list of included and excluded sources were not recorded; therefore, the number nine represents the size of the analytical set and does not constitute a basis for claiming saturation.

Extraction, Coding, and Theme Development

The extraction unit was a meaningful proposition concerning scenario construction, conditions of use, or the boundaries of inference. The evidence ledger contains 49 paraphrased units; the contributions of studies S1 through S9 were 6, 5, 7, 6, 5, 5, 5, 5, and 5 units, respectively. Each unit was recorded together with the location of the evidence, its Persian paraphrase, code, and theme. In the identifier S2.01, the first component refers to the study and the second to the unit. The units are not direct quotations from participants, and uniqueness of an identifier does not indicate independence of evidence. For example, S9.01 reports the assessment method, whereas S9.05 reports the result of the same comparison.

The analysis used sensitizing concepts and cross-study comparison. System boundary, driver, uncertainty, and impact were initial concepts derived from the research question and literature. In comparing the texts, the distinction between the existence of data and its usability, the gap between a method's theoretical capacity and its actual application, and effects outside the assessment boundary also became salient. The meaning units were organized into 18 descriptive codes, and six analytical themes were formulated by comparing their relationships and differences. A descriptive code remains close to the content of the source proposition, whereas an analytical theme represents a relationship proposed through comparison of codes in order to answer the research question. This pathway combined analysis based on initial concepts with interpretation emerging from the texts (Dixon-Woods et al., 2006; Thomas & Harden, 2008).

Assigning multiple codes to a single unit depended on the presence of a distinct component corresponding to each code within that unit's content. During codebook refinement, limitation of the study scope was distinguished from unmeasured outcomes, and indicator selection was distinguished from differentiation among impact levels.

In comparing sources, conceptual overlap, complementarity, and interpretive tension were examined. For example, the study on local energy markets combines user willingness and user intelligence within a single scenario axis, whereas the urban-planning study shows that the existence of data does not guarantee its organizational use. These two studies did not measure the same variable within a common context. Their juxtaposition provides the basis for an analytical proposition: in problems where this distinction matters, technical capability, usability, and willingness to use should be examined separately. This proposition results from comparison of the texts and does not imply proof of a causal relationship among these components (Mazumdar et al., 2023; Mirzaei Alavijeh et al., 2021).

The ledger was checked by comparing the 49 paraphrases with the relevant sections of the source studies and by structurally reviewing identifiers, assignments, and the aggregation table. Ambiguous wording and evidence locations were corrected during this process. This documentary checking differs from independent coding by a second researcher. The number and roles of analysts and the tools used for data management were not fully documented in the initial stage; therefore, intercoder agreement is not reported.

Critical Appraisal and Analytical Transparency

Critical appraisal was conducted according to study type. Common criteria included clarity of the question and context, methodological appropriateness, traceability of inference, and explicit acknowledgment of limitations. In expert-based studies, panel composition and the conversion of judgments into scenarios were examined; in model-based studies, the comparison baseline, assumptions, and impact

boundary were assessed; and in review studies, source selection and overlap of evidence were considered. The appraisal results were used to determine the boundaries within which each study could be used and were not converted into a single numerical score.

Review studies and papers derived from shared projects do not necessarily generate independent evidence. In the present interpretation, repetition of a proposition across multiple texts was not treated as grounds for increasing its weight. A distinction was also maintained among reporting actual implementation of a method, stating its limitation, and recommending its future use.

Sensitivity Analysis of Code Coverage

The sensitivity of ledger coverage to source composition was examined using a leave-one-study-out procedure. In each of the nine conditions, all units from one study were temporarily removed from the count, and the numbers of codes and themes retaining at least one supporting unit were recalculated. Three grouped-removal conditions were also examined: S3 and S4; S3, S4, and S9; and the complementary studies S5 through S7. Definitions and assignments were kept fixed, and the themes were not regenerated. This analysis is limited to ledger coverage and does not assess stability of theme meaning, independence of sources, or the practical validity of the framework. The calculation method and full output are presented in Appendix H.

Scope of the Study

The scope of this study consists of a selected body of texts concerning energy futures and is not limited to a single location or organization. The unit of analysis is published propositions concerning scenario design, conditions of technology deployment, and impact assessment; therefore, this study is not a field study conducted on a human or organizational population. The thematic focus is on the logic of scenario planning for renewable energy development, while examples related to artificial intelligence are used to illustrate application of the framework.

Geographically, the selected sources include experiences from Finland, European local energy markets with an emphasis on Sweden, energy projects and technologies in Germany, local institutions in the United Kingdom, global analyses, and Iran's energy system. The temporal horizons and scales of these studies are not identical, and comparison is conducted at the level of concepts and boundaries of inference rather than for direct generalization of findings to a specific country or organization.

The analytical set comprised nine studies with different roles: three scenario-building studies (S1, S2, and S8), two studies on scenario design and integration (S3 and S4), three complementary studies on deployment capacity or impact assessment (S5, S6, and S7), and one comparative review of participatory methods (S9). The sources were published between 2020 and 2026; this range resulted from sample selection rather than from a pre-specified temporal restriction in the search. Table 1 presents the context, method, analytical role, and inferential boundaries of each study.

Table 1

Characteristics, Analytical Role, and Inferential Boundaries of the Selected Studies

Identifier and Citation	Context and Method of the Original Study	Role in the Present Synthesis Process	Limits of Inference
S1 (Rikkonen et al., 2021)	Finland; 2030 horizon. Two-round Delphi, cluster analysis, and narrative development	Scenario building	The second round included responses from 21 participants; the article itself notes potential bias in panel composition. Expert opinion does not represent the statistical probability of a future occurring.
S2 (Mirzaei Alavijeh et al., 2021)	European local energy and flexibility markets; emphasis on Sweden; 2035. Intuitive logic, expert survey, and cross-impact analysis	Scenario building	The survey involved 14 experts and the matrix was developed by a smaller group; user willingness and user intelligence were combined within one axis. The need to separate them depends on the research question and application context.
S3 (Prehofer et al., 2021)	Three German projects at household, national, and regional scales. Reflexive case comparison, retrospective questionnaire, and qualitative content analysis	Experience-based methodological analysis	The authors participated in the projects; the three-case sample supports theoretical rather than statistical generalization. It shares part of its literature base with S4.
S4 (Weimer-Jehle et al., 2020)	Socio-technical energy scenarios; case sets from 2008 to 2019. Purposive comparison of 16 studies and synthesis of CIB experience	Methodological review	The review is selective; its underlying evidence overlaps with some sources used in this article. Repetition of a result alone does not constitute new independent evidence.

S5 (Haase et al., 2022)	Energy technologies in the German context; 2050 horizon. Prospective sustainability assessment framework and application to three technology domains	Impact assessment; complementary evidence	The article explicitly notes limitations of social indicators and the assessment boundary; technology estimates are not equivalent to realized futures.
S6 (Mazumdar et al., 2023)	Seven UK local authorities; interviews conducted in 2020; target issue 2050. Semi-structured interviews with 14 stakeholders and thematic analysis	Implementation capacity; complementary evidence	The study does not construct renewable-energy scenarios; it is used to identify data and organizational constraints, not to prove AI effects or the current situation in Iran.
S7 (Stern et al., 2025)	Electricity, food, and mobility at the global scale; 2035 horizon. Perspective article with conditional modeling of an AI scenario and baseline	Impact estimation; complementary evidence	Rebound effects were not included in the calculations; estimates depend on assumptions regarding adoption, efficiency, and emissions intensity and do not represent realized outcomes.
S8 (Fathi & Mirsaeid Ghazi, 2026)	Climate-responsive energy systems in Iran. Review and interviews, a 15-expert panel, MICMAC, and four scenario narratives	AI and energy scenario building	The scope extends beyond renewable energy, and scenarios depend on panel judgments. Structural influence is not equivalent to future uncertainty. An inconsistency in the total row of Table 4 of the source was recorded in the critical appraisal; those figures were not used for weighting in this meta-synthesis.
S9 (Campfens et al., 2025)	Participatory modeling in energy-transition scenarios. Review of 48 articles and five expert interviews in the original study	Methodological review; counter-evidence	Theoretical capacity was distinguished from reported application. Failure to report explicit integration in the reviewed sample does not prove the absence of implicit integration or hybrid methods in the broader literature.

3. Findings and Results

The analytical ledger contains 49 meaning units, 18 descriptive codes, and six analytical themes. In total, 74 unit–code links and 64 unit–theme links were recorded; the difference between these numbers and the number of units results from multiple assignment. All codes are supported by at least one unit. These counts describe the structure of the ledger rather than causal strength, policy priority, or probability of future occurrence. Table 2 illustrates examples of the inferential pathway.

Table 2

Examples of the Inferential Pathway from Evidence to Code and Analytical Interpretation

Paraphrased Evidence and Source	Related Codes	Interpretation Derived from Comparison
S3.02: Linking global, national, and sectoral matrices in one of the integration experiences (Prehofer et al., 2021).	C02: Linking scales	A local scenario should make explicit its relationship to assumptions at higher scales; this relationship does not imply automatic consistency.
S2.03: The user axis includes participation and digital capability; S6.01: the existence of data is not equivalent to its use (Mazumdar et al., 2023; Mirzaei Alavijeh et al., 2021).	C04: Participation and authority; C05: Data and organizational capability	Technical capability and usability can be separated for specific analytical problems.
S2.01: Expected influence of factors and their future uncertainty were assessed separately (Mirzaei Alavijeh et al., 2021).	C08: Influence versus uncertainty	Selection of scenario axes cannot be justified solely by listing highly influential factors.
S4.03–04: Consistency among states and translation of narratives into parameters are two distinct activities (Weimer-Jehle et al., 2020).	C10: Structural consistency; C11: Qualitative–quantitative translation	The logic by which states are combined should be reviewable before and alongside interpretation of quantitative outputs.
S5.03 and S7.04: The comparison reference changes the result, and rebound effects were omitted from one estimate (Haase et al., 2022; Stern et al., 2025).	C14: Assessment boundary and comparison reference; C15: Omitted and side effects	An in-model result cannot be converted into a net system benefit without examining the assessment boundary.
S9.01: Theoretical capability of a method was distinguished from observed application (Campfens et al., 2025).	C17: Limits of generalization and self-critique	The theoretical capability of a method alone is not evidence of its effectiveness in real-world application.

Note: All scales use 400 respondents. Confidence intervals for α are based on 2,000 respondent bootstrap samples stratified by neighborhood. ω_{total} is derived from the correlated eight-domain model.

Problem Framing and Contextualization of the Future

The first theme indicates that a scenario, before being a collection of drivers, is a response to a bounded and specific question. The local energy-market study defines the topic

and the 2035 horizon before constructing the scenario matrix. By contrast, the assessment of energy technologies in Germany is conducted with a 2050 horizon and specific functional boundaries. This difference is not merely a difference in end year; the unit of analysis, the type of decision, and the criterion against which the outcome is assessed also change (Haase et al., 2022; Mirzaei Alavijeh et al., 2021). The supporting units for this comparison are S2.02 and S5.01.

At multiple scales, the conditional nature of results becomes even more important. Prehofer and colleagues describe an example in which a national scenario serves as the context for regional analysis. The resulting interpretation is that such an extension allows examination of futures within that context but does not necessarily capture changes in the national context itself. Accordingly, a global or national reference should be recorded as a constraining assumption rather than as a future whose occurrence is certain. This interpretation is consistent with the literature on linking scenarios across geographical scales (Prehofer et al., 2021; Zurek & Henrichs, 2007).

For scenario planning in solar or wind energy, it should be made explicit whether the decision under consideration concerns capacity expansion, utilization of existing capacity, project ownership, or deployment of a specific technology. A scenario suitable for analyzing production growth does not necessarily provide sufficient information about household access. Recording this distinction from the outset prevents expansion of the inferential scope at the end of the analysis.

Actor Agency and Deployment Capacity

The second theme emerges from juxtaposing evidence that considers technology in relation to users and organizations. In local energy markets, the presence of smart equipment and user participation is examined in interaction with grid-operator incentives. In the study by Mazumdar and colleagues, the problem is not merely the absence of data; fragmented information, incompatible formats, lack of skills, and dependence on suppliers are also identified. Deployment therefore depends on the simultaneous presence of several capabilities and cannot be inferred from a single hardware indicator (Mazumdar et al., 2023; Mirzaei Alavijeh et al., 2021). This comparison is based on S2.03 and S6.01 through S6.04.

For artificial intelligence scenarios, generation of a recommendation by a system differs from an organization's capacity to use that recommendation continuously. Fathi and Mirsaeid Ghazi also identify data, infrastructure, human capital, and financial resources among factors shaping the future of the energy system. In the present synthesis, "deployment capacity" refers to a combination of technical capability, organizational resources, and authority or motivation to use the technology. This concept is not a composite indicator with empirically measured weights but rather an analytical distinction for examining the conditions under which technology can be used (Fathi & Mirsaeid Ghazi, 2026; Mazumdar et al., 2023).

Combining capability and willingness within a single scenario axis may reduce the number of states but can obscure the difference between an "equipped but distrustful user" and a "willing user without access." Whether these states need to be distinguished depends on the research question and context. The synthetic conclusion is therefore the need to examine this distinction before merging variables, rather than a general rejection of simplified axes.

Transforming Drivers into Uncertain Future States

The third theme concerns the transition from naming factors to defining future states. In Cross-Impact Balance (CIB) analysis, descriptors are specified through alternative states; labels such as investment, technology, or participation alone are insufficient for examining consistency. Influence must also be distinguished from future uncertainty. In the present interpretation, defining states involves specifying the relevant dimension, time horizon, and logic of change and cannot be achieved simply by converting positive wording into negative wording (Mirzaei Alavijeh et al., 2021; Weimer-Jehle et al., 2020). Direct evidence for this distinction is recorded in S2.01 and S4.02.

In the Finnish study, expected and preferred futures were elicited separately, and disagreement regarding some forms of support remained alongside areas of consensus. This feature prevents all judgments from being reduced to a single "probable future." In the present synthesis, uncertainty is represented as a question concerning the pathway and conditions of change: for example, to what extent will energy data become interoperable during the study horizon, and what conditions could alter this trajectory? The answer to such a question should be supported by evidence and reasoning; the generic label "technological growth" cannot substitute for it (Rikkonen et al., 2021).

The output of this theme is a set of questions for identifying uncertainties relevant to the problem. Determining final scenario axes requires consideration of the decision scope, time horizon, relationships among factors, and contextual evidence. This meta-synthesis does not yield

a ranking of drivers or the selection of two definitive scenario axes for Iran.

Consistency and Translation Between Narrative and Model

Within this theme, consistency among states is distinguished from translation of narrative into model inputs. CIB analysis examines internal consistency among combinations of states on the basis of entered relationships and judgments; this output is neither an estimate of occurrence probability nor empirical validation of the narrative. Computational consistency also does not eliminate limitations arising from how factors were defined or from the initial judgments (Weimer-Jehle et al., 2020). This proposition is tracked in the ledger through S4.03 and code C10.

Prehofer and colleagues show that the timing of involvement of narrative developers and modelers and the manner in which disagreements are addressed differ across designs. A phrase such as "widespread adoption" may be translated into different growth rates, scopes of use, or constraints. Accordingly, documenting the source of a parameter, the rule used to convert a qualitative proposition into a quantitative value, and the limits of that conversion forms part of scenario documentation. In this article, such documentation is termed a "translation bridge" (Prehofer et al., 2021).

The relationship between narrative and model should permit feedback: a model may reveal technical constraints within a narrative, while a narrative may challenge the social or institutional assumptions of a model. The review by Weimer-Jehle and colleagues demonstrates a distinction between recommending such feedback and actually implementing it. Therefore, in the proposed framework, in addition to inputs and outputs, the reason for modifying a narrative or parameter and the implications of that modification for scenario interpretation are recorded (Weimer-Jehle et al., 2020).

Multidimensional Outcomes and the Boundaries of Sustainability Claims

The fifth theme emphasizes distinctions among levels of outcomes. The Finnish study examines changes in the share of renewable energy alongside changes in total demand. In the analysis by Stern and colleagues, the effect of artificial intelligence on technology adoption is likewise distinguished from its effect on integration and utilization of renewable resources. Thus, an increased share, increased usable generation, and reduced emissions are not synonymous indicators and may not follow identical trajectories under different conditions (Rikkonen et al., 2021; Stern et al., 2025). Evidence for this distinction is recorded in S1.04 and S7.02.

The assessment by Haase and colleagues demonstrates that the choice of reference system, assessment boundary, and sustainability indicators affects the result of technology comparisons. Stern and colleagues also explicitly state that rebound effects were not included in their calculations. Accordingly, any claim derived from an estimate should remain bounded by the corresponding assessment boundary and assumptions, and unmeasured effects should also be identified (Haase et al., 2022; Stern et al., 2025).

To operationalize this distinction, an "impact ledger" is proposed in which measured impacts, impacts that are only described, and effects outside the assessment are recorded separately. In AI applications, such a ledger may distinguish among model accuracy, organizational use, operational performance, and net environmental impacts. This separation clarifies the scope of claims regarding the benefits or harms of a technology (Kaack et al., 2022).

Critical Scrutiny, Reflexivity, and Learning

The sixth theme emerges from explicit acknowledgment of limitations in the original studies and from comparison between theoretical capacity and actual application. Rikkonen and colleagues discuss limitations in panel composition; Prehofer and colleagues characterize inference from their own experiences as theoretical generalization; and Campfens and colleagues distinguish the theoretical capacity of participatory methods from their reported performance. These distinctions serve as a reminder that the name of a method alone does not guarantee the quality or validity of its results (Campfens et al., 2025; Prehofer et al., 2021; Rikkonen et al., 2021).

Reflexivity in the proposed framework involves recording supporting evidence, alternative interpretations, and information that could change an analytical decision. S2.05 reports revision of narratives; S4.06 demonstrates the gap between recommending iteration and actually implementing it; and S5.05 proposes reconsideration of the positioning and basis for selecting social indicators in future assessments. All three units are associated with C18, but an action actually undertaken and a recommendation for future research represent two different forms of evidence (Haase et al., 2022; Mirzaei Alavijeh et al., 2021; Weimer-Jehle et al., 2020).

Sensitivity of Ledger Coverage to the Selected Studies

When each of the nine studies was removed separately, all six themes still retained at least one supporting unit;

however, removal of S2, S3, and S4 eliminated direct support for C08, C02, and C10, respectively. Thus, retaining the labels of all six themes does not mean that all of their components remain supported. When S3, S4, and S9 were removed simultaneously, only two units from S1 remained under theme T4; these concern transformation of Delphi findings and narrative development and do not substitute for specific evidence on linking narrative and energy models. Likewise, removal of the complementary studies S5 through S7 left codes C14 and C15 unsupported and only one unit supporting T5. These results reveal the role of methodological and complementary sources rather than the empirical robustness of the framework (Appendix Tables H-1 and H-2).

Functions and Outputs of the Framework

The six themes are translated into six functions within scenario design. Problem and context definition specifies the decision scope; actor analysis clarifies deployment conditions; definition of states formulates uncertainty questions; consistency and translation analysis links narrative with models; impact assessment determines the boundaries of inference; and reflexivity enables revision of the stages. These functions are iterative, and tool selection at each stage should be aligned with the problem.

Table 3

Functions, Outputs, and Control Questions of the Proposed Framework

Function	Expected Output	Control Question and Supporting Evidence
1. Defining the problem and context	Definition of the decision, technology scope, unit of analysis, baseline year, and horizon; recording selected national or global contexts.	To which scope and contextual assumptions is the result conditional? (Mirzaei Alavijeh et al., 2021; Prehofer et al., 2021)
2. Identifying actors and deployment capacity	Mapping of roles, access, resources, skills, and motivation to use; recording the distinction between technical capability and actual use.	Who is able to use the technology, and who has the authority or practical capacity to use it? (Mazumdar et al., 2023; Mirzaei Alavijeh et al., 2021)
3. Defining drivers and future states	Precise descriptors, alternative states, and justification of the importance and uncertainty of each factor.	Have the factor, state, and outcome been distinguished from one another? (Walker et al., 2003; Weimer-Jehle et al., 2020)
4. Examining consistency and the translation bridge	Recording assumed relationships, narrative logic, sources of parameters, and changes resulting from interaction between narrative developers and modelers.	Are the combination of states and qualitative–quantitative translation reviewable? (Prehofer et al., 2021; Weimer-Jehle et al., 2020)
5. Examining conditional impacts	Ledger of indicators, comparison baseline, life-cycle boundary, and unmeasured effects.	Which outcomes were calculated, which were described, and which were omitted? (Haase et al., 2022; Stern et al., 2025)
6. Reflexivity and learning	Recording disagreements, sensitive assumptions, signals of change, and revised versions.	What new evidence could change the framework or narrative? (Campfens et al., 2025; Rikkonen et al., 2021)

Distinguishing Future Uncertainties from Methodological Choices and Impact Indicators

Not all questions in scenario design concern future uncertainty. Access to data or continuity of deployment resources may relate to an unknown future state of the system; however, transparency in translating narratives into models and selection of the assessment boundary are primarily methodological decisions or criteria. Energy generation and emissions reduction are likewise outcomes used for comparing scenarios. Table 4 distinguishes these positions. The states presented in the table are conceptual examples and were not derived from new interviews, expert rankings, or measurement of conditions in Iran. Converting candidate issues into scenario axes requires specification of the horizon, distinction among states, and assessment of their importance and uncertainty in the context under examination.

Table 4

Operational Questions According to Their Position in Scenario Design and Evaluation

Position in the Analysis	Question and Example State or Choice	Indicator and Supporting Evidence
Contextual condition; candidate uncertainty	Macro context: How do national or global assumptions change? Example: continuity of selected assumptions; gradual change; contextual disruption.	Recording external assumptions and the range of their possible change. (Prehofer et al., 2021; Zurek & Henrichs, 2007)
Candidate system uncertainty	Data: What level of operational access exists over the study horizon? Example: limited access; contractual access for specified actors; broad access. Data quality should be assessed separately.	Coverage of access, retrieval delay, and interoperability. (Mazumdar et al., 2023)

Candidate system uncertainty	Actors: How are capability and willingness to use combined? Example: both capability and willingness limited; capability without willingness; willingness without opportunity; alignment of capability and willingness.	Distinguishing access and authority from willingness and actual use. (Mirzaei Alavijeh et al., 2021)
Candidate system uncertainty	Deployment resources: How stable is resource provision over the study horizon? Example: temporary support; unstable provision; continuous provision.	Continuity of funding, skills, and operational support. (Fathi & Mirsaeid Ghazi, 2026; Mazumdar et al., 2023)
Methodological quality criterion; not a future axis	Narrative–model translation: Is the source of each parameter and the conversion rule clear? Levels of assessment: implicit conversion; documented without feedback; reciprocal and documented revision.	Recording parameter origin, reasons for change, and interpretive disagreement. (Prehofer et al., 2021; Weimer-Jehle et al., 2020)
Outcome variable for comparison	Renewable-energy development: By which indicator is the result measured? Distinct indicators: installed capacity, usable generation, renewable share, and emissions.	Recording the definition, unit, baseline year, and horizon of each indicator. (Rikkonen et al., 2021; Stern et al., 2025)
Assessment-boundary choice	Net impact: Which effects are included in the calculation? Scope options: direct effects; life-cycle and use-phase effects; systemic effects and estimation limitations.	Recording the baseline, system boundary, and unmeasured effects. (Haase et al., 2022; Kaack et al., 2022)
Review mechanism	Learning: What evidence triggers revision? Options: periodic review; revision upon observation of a change signal.	Recording versions, disagreements, and reasons for revision. (Campfens et al., 2025; Weimer-Jehle et al., 2020)

The application of artificial intelligence to the operation of solar and wind resources provides an example for explaining the framework. In this example, the status of technology use should be distinguished from the consequences of its use; two organizations with similar access to the same technology may differ in terms of data, decision authority, implementation quality, and grid conditions. These differences are important for defining deployment capacity and assessment boundaries. The present example concerns potential effects of application and does not represent the findings of a field study on Iran (Fathi & Mirsaeid Ghazi, 2026; Kaack et al., 2022; Stern et al., 2025).

For example, consider the focal decision to be "deployment of a generation-forecasting system by a renewable-energy operator." Evidence concerning data and organizational use presented in Table 2 supports the deployment-capacity theme. Based on this theme, the state "standardized data are available, but operational use remains limited" may be proposed for examination. This state illustrates that improved forecasting alone does not determine whether recommendations will be used in operations. The narrative should explain who has the authority to use the output and which organizational constraints may prevent implementation.

4. Discussion and Conclusion

The present study sought to move beyond the conventional identification of renewable-energy drivers by reconstructing how selected studies transform evidence into scenario logic. The interpretive meta-synthesis yielded six analytical themes: problem framing and contextualization of the future; actor agency and deployment capacity; transformation of drivers into uncertain future states; consistency and translation between narrative and model; multidimensional outcomes and the boundaries of sustainability claims; and critical scrutiny, reflexivity, and learning. These themes indicate that scenario construction is not adequately represented as a linear sequence beginning with a list of influential variables and ending with several alternative narratives. Rather, scenario design appears to be an iterative analytical process in which the meaning of a driver depends on the decision problem, spatial and temporal context, actor capabilities, assumptions about future states, modeling choices, and the outcome boundary used for evaluation. This interpretation is consistent with scenario-planning literature emphasizing that scenarios differ according to their purpose, temporal orientation, and relationship to uncertainty and decision support (Amer et al., 2013; Börjeson et al., 2006; Skea et al., 2021). The findings therefore support a shift from driver identification as an endpoint toward driver interpretation as one component within a broader and traceable scenario-design architecture.

The first theme, problem framing and contextualization of the future, showed that the same factor may carry different analytical meaning depending on the unit of analysis, geographic scale, baseline, horizon, and decision under consideration. The synthesis demonstrated that a scenario constructed for local flexibility markets cannot automatically be transferred to national renewable-energy expansion, just as a technology assessment with a 2050 horizon cannot be interpreted as equivalent to a market scenario for 2035. This result aligns with work showing that scenario purpose and scale shape both scenario construction and interpretation (Börjeson et al., 2006; Skea et al., 2021). It is also compatible with findings on cross-scale scenario linkage, which show that higher-level assumptions may

function as contextual constraints rather than fixed predictions (Zurek & Henrichs, 2007). In methodological terms, the result reinforces the importance of making explicit which assumptions are treated as background conditions and which are allowed to vary within the scenario space. The integration of national, regional, and sectoral scenarios described in energy-transition research similarly indicates that contextual linkage must be documented if results are to remain interpretable across scales (Pregger et al., 2020; Prehofer et al., 2021).

The second theme concerned actor agency and deployment capacity and was one of the most important interpretive contributions of the synthesis. The findings showed that technical availability, organizational ability to use a technology, and willingness or authority to use it should not be treated as equivalent. This distinction emerged clearly from the comparison between local energy-market scenarios and studies of organizational constraints in integrated urban planning. The result is consistent with evidence that data availability alone does not guarantee effective use because organizations may face fragmented information systems, insufficient skills, limited internal capacity, or dependence on external providers (Mazumdar et al., 2023). It is also supported by research on energy transitions emphasizing the importance of stakeholder participation, institutional capability, and implementation arrangements rather than technological infrastructure alone (Campfens et al., 2025). From this perspective, deployment capacity is better understood as a relational construct combining resources, competencies, authority, incentives, and institutional conditions. This interpretation extends technological scenario analysis by showing that operationalization depends on more than the presence of hardware or software.

This distinction is particularly relevant to artificial intelligence in energy systems. The present study found that a recommendation generated by an AI system should not be treated as equivalent to organizational adoption or operational use. Previous studies similarly suggest that AI-related climate benefits are conditional on the presence of appropriate data, governance, infrastructure, institutional alignment, and implementation capacity (Kaack et al., 2022; Stern et al., 2025). Scenario-oriented research on climate-responsive energy systems also identifies data, infrastructure, human capital, and financial resources as important drivers of future AI-enabled energy development (Fathi & Mirsaeid Ghazi, 2026). Taken together, these findings support the analytical separation of technological capability from deployment capacity. They also suggest that scenarios that combine willingness and capability within one axis may be useful for simplification but risk masking distinct implementation pathways, such as situations where actors are motivated but lack access or possess resources but lack incentives or trust.

The third theme concerned the transformation of drivers into uncertain future states. The findings showed that influential factors are not automatically suitable as scenario axes and that a meaningful scenario requires explicit specification of alternative states. This is consistent with established uncertainty literature, which distinguishes between uncertainty concerning the future state of a system and the importance or impact of a variable within that system (Walker et al., 2003). The result is also aligned with scenario studies in which expected influence and uncertainty are assessed separately rather than merged into a single ranking (Mirzaei Alavijeh et al., 2021). The Finnish Delphi study similarly demonstrates that expected and preferred futures should be distinguished, because normative desirability and anticipated likelihood represent different forms of judgment (Rikkonen et al., 2021). The present synthesis therefore supports a more disciplined use of the term “driver,” in which a driver should be linked to a defined dimension, plausible states, a temporal horizon, and a rationale for change. Such specification is necessary if drivers are to function analytically rather than merely descriptively.

The fourth theme, consistency and translation between narrative and model, highlights a central methodological problem in mixed qualitative–quantitative scenario design. The synthesis showed that checking internal consistency among scenario states is analytically distinct from translating narrative statements into model parameters. This distinction is strongly supported by previous research on socio-technical energy scenarios, which has shown that narrative–model integration requires explicit methodological choices and cannot be reduced to mechanical conversion (Prehofer et al., 2021; Weimer-Jehle et al., 2020). The present results suggest that transparency should be maintained regarding the origin of parameters, the reasoning used to convert qualitative propositions into quantitative assumptions, and the way disagreements between modelers and narrative developers are resolved. This interpretation is also consistent with broader scenario-planning literature, which emphasizes that scenario credibility depends on transparency in assumptions and internal logic rather than on narrative plausibility alone (Amer et al., 2013). The proposed “translation bridge”

therefore provides a practical means of tracing how meaning changes when qualitative descriptions are converted into quantitative inputs.

The fifth theme focused on multidimensional outcomes and the boundaries of sustainability claims. The synthesis demonstrated that installed capacity, usable generation, renewable-energy share, emissions reduction, and broader sustainability outcomes are analytically distinct and should not be treated as interchangeable. This finding accords with prospective sustainability assessment research, which emphasizes the importance of system boundaries, reference systems, and indicator selection in determining conclusions about technology performance (Haase et al., 2022). It also aligns with broader assessments of renewable energy, where environmental and technical benefits depend on system integration, technology characteristics, and contextual conditions (Ellabban et al., 2014). In the present synthesis, the distinction between in-model performance and net developmental benefit was especially important. A modeled technical improvement may be real within the defined system boundary while still failing to demonstrate a broader social or environmental gain.

This finding is also supported by studies of AI and climate mitigation, which warn that apparently beneficial efficiency effects may be reduced or altered by indirect and rebound effects (Kaack et al., 2022; Stern et al., 2025). The omission of rebound effects from some estimates does not invalidate the estimates themselves, but it limits the claim that may reasonably be made from them. The present framework therefore proposes separating measured outcomes, described but unmeasured consequences, and effects outside the assessment boundary. This distinction is methodologically important because sustainability claims often expand beyond the evidence actually generated. By explicitly recording which impacts are calculated, which are assumed, and which are omitted, scenario-based evaluations can become more disciplined and more transparent.

The sixth theme, critical scrutiny, reflexivity, and learning, showed that methodological self-critique is not peripheral to scenario design but an integral part of it. The reviewed studies contained explicit limitations regarding panel composition, case selection, indicator choice, participatory-method performance, and implementation conditions. These findings are consistent with interpretive synthesis methodology, which emphasizes the importance of examining the conditions under which claims are produced rather than simply aggregating conclusions (Dixon-Woods et al., 2006). They also accord with qualitative synthesis approaches that treat analytical themes as interpretive constructions requiring transparency and traceability (Thomas & Harden, 2008). Reflexivity is therefore important not only for the researcher conducting the synthesis but also for scenario developers, who should document competing interpretations, sensitive assumptions, and the evidence that could justify future revision.

The sensitivity analysis provided further support for this interpretation. Although all six themes remained represented after removal of each individual study, some specific codes lost their direct support when particular sources were excluded. This result shows that thematic persistence should not be confused with robustness of all underlying components. The finding is important because interpretive syntheses often contain conceptual redundancy at the thematic level while remaining dependent on a small number of studies for specific distinctions. The study therefore contributes a useful methodological caution: robustness should be examined both at the level of broad themes and at the level of specific analytical components. This logic is consistent with purposive qualitative synthesis, where information richness and conceptual contribution may be more relevant than numerical representativeness (Ames et al., 2019). It also supports transparent reporting of source selection and synthesis procedures as emphasized by ENTREQ and PRISMA-oriented reporting principles (Page et al., 2021; Tong et al., 2012).

The findings also clarify the value of participatory and narrative approaches. Storytelling and anticipatory narratives can make energy futures more socially meaningful and reveal assumptions that are difficult to represent quantitatively (Dahlgren et al., 2024; Sol Cueva, 2025). Research on socially engaging energy transitions likewise shows that narratives and policy expectations shape how future pathways are interpreted and legitimized (Campos et al., 2024). However, the present synthesis indicates that narrative richness should be accompanied by analytical traceability. A compelling story is not sufficient if the relationship between the narrative, its drivers, actor assumptions, model parameters, and outcome criteria cannot be reconstructed. The value of narrative therefore lies not in replacing formal analysis but in complementing it within a documented chain of reasoning.

A similar conclusion applies to participatory modeling. Participation can enrich scenario design by incorporating diverse forms of knowledge, but its contribution depends on the function it serves and how stakeholder input is integrated into analysis (Campfens et al., 2025). The present

framework helps distinguish consultation, knowledge elicitation, model input, validation, and reflexive learning as potentially different participatory roles. This distinction matters because participation may otherwise be described as a general methodological strength without showing how it actually changes the scenario. The framework thus provides a way to connect participatory input to specific analytical outputs rather than treating participation as a procedural label.

The broader implication is that renewable-energy scenario research would benefit from treating scenario construction as an auditable chain of transformations. Evidence is interpreted into codes, codes into themes, themes into scenario functions, drivers into states, narratives into parameters, and model outputs into evaluative claims. At each transition, analytical choices are introduced. Making these choices visible improves the possibility of review, replication, and revision. This is especially important in energy-transition contexts characterized by rapid technological change, uncertain policy environments, and evolving organizational capabilities. Studies of renewable-energy futures in Iran and other settings already show that policy, infrastructure, finance, technology, and institutional arrangements jointly shape future pathways (Fathi & Mirsaeid Ghazi, 2026; Ghouchani et al., 2021). A traceable framework does not remove these uncertainties, but it can make explicit how they are represented and how they influence scenario conclusions.

The study has several limitations. First, the analytical set was purposively selected and was not designed to provide exhaustive coverage of the renewable-energy scenario literature. Second, the nine studies differed substantially in geographic context, methodology, scale, and analytical purpose, which strengthened conceptual diversity but limited direct comparability. Third, several reviewed studies were methodologically related or drew from overlapping research traditions, meaning that apparent repetition of findings cannot be interpreted as fully independent corroboration. Fourth, the coding process was not independently replicated by a second coder, and intercoder reliability was therefore not assessed. Fifth, the leave-one-study-out analysis evaluated structural coverage of codes and themes rather than semantic stability, causal validity, or predictive usefulness. Finally, the resulting framework is conceptual and has not yet been prospectively tested in a real scenario-design process or compared empirically with alternative scenario methodologies.

Future research should test the proposed framework in prospective case studies across different renewable-energy contexts, including national planning, regional energy transitions, utility-level decision-making, and organizational deployment of digital technologies. Comparative studies could examine whether the six proposed functions remain stable across solar, wind, storage, hydrogen, and smart-grid scenarios. Further work should also operationalize deployment capacity and examine whether technical capability, organizational usability, authority, and willingness can be measured independently and combined meaningfully. Methodological research could evaluate the proposed translation bridge by tracking how qualitative scenario statements are converted into quantitative model assumptions and how these choices affect model outputs. Future studies should also examine whether sensitivity analysis at the code, theme, and scenario-function levels improves interpretive robustness. Finally, empirical validation should assess whether the framework improves transparency, stakeholder understanding, reproducibility, and decision quality compared with conventional scenario-design procedures.

For practice, scenario-development teams should begin by defining the decision problem, system boundary, time horizon, and contextual assumptions before identifying drivers. Drivers should then be separated from uncertain future states and from outcome indicators. Technical capability should be assessed separately from organizational capacity and willingness to use a technology, especially in AI-enabled energy applications. Narrative developers and modelers should document how qualitative statements are translated into numerical parameters and should record the source and rationale for each major assumption. Impact assessment should distinguish calculated outcomes from descriptive claims and omitted effects, while all major limitations and alternative interpretations should be retained in an explicit evidence ledger. Scenario exercises should also include scheduled review points so that narratives, assumptions, and parameters can be revised when new evidence, policy changes, or technological developments emerge.

Authors' Contributions

Authors contributed equally to this article.

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In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

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