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Exploring stakeholder engagement in energy system modelling and planning: a systematic review using SWOT analysis

Abstract: The global energy transition toward sustainability requires frameworks that integrate technical, economic, and social aspects. Stakeholder involvement is crucial in energy system modeling and planning. This study systematically reviews stakeholder involvement techniques in energy system modeling by employing a SWOT analysis to evaluate engagement strategies. It aims to examine the effectiveness of various approaches to stakeholder participation and explore approaches for incorporating stakeholders into decision-making to enhance public trust and acceptance of energy transition models. This study identifies and analyses three primary engagement approaches: information, consultation, and collaboration. A SWOT analysis was conducted to assess the strengths and weaknesses of each approach. The information approach effectively disseminates knowledge but is limited by its unidirectional nature. The consultation approach facilitates two-way dialogue but may struggle to incorporate stakeholder input effectively. The resource-intensive collaborative approach offers opportunities for enhanced knowledge sharing and ongoing stakeholder engagement. The study concludes that informational and consultative approaches are the most effective when utilized as components of a broader collaborative framework. These

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findings contribute to the knowledge base for modelers, policymakers, and researchers engaged in energy transition planning and offer valuable insights for developing more socially equitable energy transition strategies.

KEYWORDS: stakeholder engagement, SWOT analysis, energy system modelling, sustainable energy transitions, collaborative decision-making

Introduction

The global transition toward sustainable energy systems necessitates frameworks and tools that integrate technical, economic, and social aspects to inform decision-making processes. Simulation and optimization models are crucial for examining the economic and technical aspects of energy systems, thereby supporting policy decisions for future energy system analyses (Sovacool et al. 2015). The energy system model (ESM) has emerged as a crucial tool for simulating and assessing the transition pathways. While conventional ESM approaches have predominantly emphasized quantitative elements, the increasing complexity of energy systems underscores the need to incorporate societal perspectives to ensure equitable and feasible solutions. The significant shift towards a more distributed and sustainable energy infrastructure requires not only the embrace of technological advancements but also the proactive involvement of stakeholders in the transformation process (Liegl et al. 2023). Therefore, stakeholder engagement is no longer an optional component but a fundamental aspect of effective energy system planning.

In ESM, there is an increasing trend toward involving diverse stakeholders, including energy and environmental experts, social scientists, industry professionals, civil society groups, the public, and government entities (Amin et al. 2024). Stakeholder involvement is essential for comprehensive social representation in energy models, enhancing the relevance and public acceptance of modeling outputs. The study by McGookin et al. (2024) emphasized the importance of incorporating a diverse range of stakeholders, including citizens, in energy system modeling. This highlights that current modeling practices often overlook the systematic involvement of citizens, which is crucial for understanding the impact of energy policies on the public. The study concludes with reflections on key challenges and areas for future research, identifying gaps in well-structured, participatory, collaborative processes in energy modeling (ibid). Consistent with the approach described in Ref. (McGookin et al. 2021), this study conducted a systematic review of stakeholder involvement techniques in energy system modeling and planning. The review revealed that only a small fraction of studies reported collaboration with non-academic stakeholders, indicating a significant gap in effective stakeholder engagement practices. This suggests that many energy planning initiatives may not fully utilize stakeholder input, which is essential for understanding the effectiveness of various participation approaches (ibid). However, the degree and effectiveness of stakeholder engagement vary significantly across projects, resulting in deficiencies in terms of inclusiveness and practical application.

SWOT analysis, a technique employed across numerous fields, facilitates the identification of actionable insights by evaluating internal strengths and weaknesses against external opportunities and threats (Benzaghta et al. 2021). When applied to stakeholder engagement in ESM, this analytical approach enables a systematic assessment of various approaches (McGookin et al. 2021; McGookin et al. 2024; Trutnevyte and Stauffacher 2012). This study utilized a SWOT framework to evaluate stakeholder engagement critically approaches in ESM. This study examines the specific advantages and limitations of different approaches, comparing them based on the decision-making process that could lead to enhanced policy outcomes and increased public acceptance. This is crucial because public acceptance in decision-making procedures is fundamental to the successful development of energy planning and policies. While the significance of stakeholder involvement in energy planning is widely recognized, previous research has not comprehensively evaluated the advantages and disadvantages of various engagement methods utilizing a structured SWOT analysis. This study presents an innovative comparative assessment that aids policymakers in identifying the most appropriate approach to incorporating stakeholder inputs into sustainable energy transformations.

Consequently, this study aims to achieve the following goals:

1. To understand the effectiveness of various approaches to stakeholder participation in energy planning initiatives.

2. To explore the most appropriate approach for incorporating stakeholders into decision-making to enhance public trust and acceptance of energy transition models.

The findings of this study make significant contributions to the body of knowledge of scholars, government officials, and specialists engaged in energy transition planning. This study enhances energy system modeling by presenting a systematic evaluation of stakeholder involvement, which is crucial for developing socially equitable energy transition strategies. It addresses the necessity of incorporating diverse perspectives into the formulation of equitable policies for transitioning to future energy systems.

1. Methods

Figure 1 outlines the methodological approach employed in this study, which aims to provide a comprehensive analysis of the existing literature on stakeholder engagement strategies and examine the most effective approach for planning and decision-making in energy systems.

This study employed a systematic examination of stakeholder involvement techniques, adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2025) guidelines. The systematic review process used in this study is illustrated in Figure 2.

In the second phase, the results were refined by examining abstracts, yielding 108 relevant publications. This critical phase refined the selection of articles into those deemed potentially relevant based on their abstracts. The inclusion criteria were established to identify studies

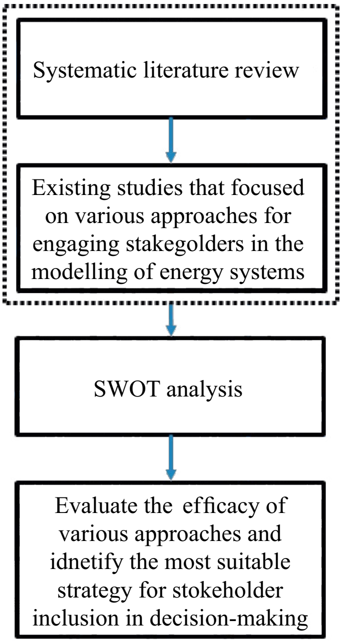

Fig. 1. The methodological framework employed in this study

Rys. 1. Ramy metodologiczne zastosowane w niniejszym opracowaniu

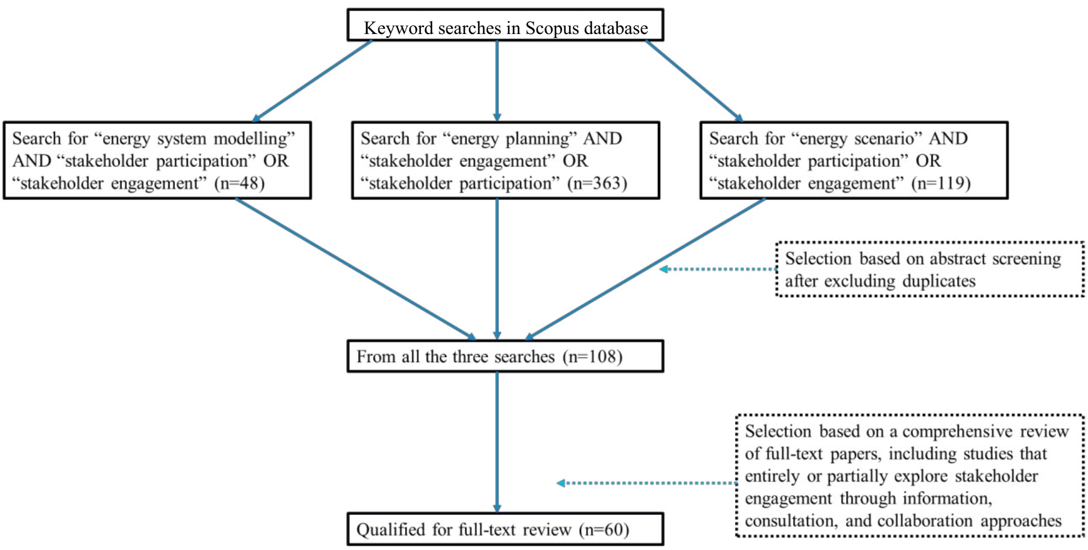

Fig. 2. Systematic review of stakeholder engagement approaches

Rys. 2. Systematyczny przegląd podejść do zaangażowania interesariuszy that utilized various methodologies, including public presentations, questionnaires, interviews, semi-structured discussions, workshops, meetings, and stakeholder input scenarios, in energy system modeling and planning at urban or national scales. A subsequent full-text review of these 108 publications identified 60 publications that were wholly or partially dedicated to exploring information dissemination, consultation processes, and collaborative approaches for incorporating stakeholders in energy system modeling and planning. These 60 publications constitute the foundation of this review, and a summary is provided in Appendix A (Table 5).

The SWOT framework, which evaluates organizational strategies, emerged in the early 1950s (Benzaghta et al. 2021). A SWOT analysis, which stands for Strengths, Weaknesses, Opportunities, and Threats, is a carefully structured strategic planning tool. This analytical framework encompasses both internal and external evaluation criteria. Internal factors enable the assessment of strengths and weaknesses, whereas external factors help to identify opportunities and threats. The SWOT analysis has been extensively embraced by scholars in the field of energy planning (Madurai Elavarasan et al. 2020). The three primary stakeholder engagement approaches – information, consultation, and collaboration – possess distinct advantages and disadvantages. Although energy planning frequently utilizes techniques such as Multi-Criteria Decision Analysis (MCDA) and Delphi methods, SWOT analysis was selected for its systematic approach to assessing the internal and external factors that influence stakeholder engagement strategies. In contrast to MCDA, which emphasizes quantitative ranking, SWOT facilitates a more nuanced examination of qualitative aspects, including trust, knowledge sharing, and public acceptance. For instance, Ref. (Terrados et al. 2007) employed SWOT analysis for regional energy planning, whereas Ref. (Srivastava et al. 2005) implemented this in municipal waste management.

2. Results

2.1. Stakeholder Engagement Strategies

The involvement and inclusion of stakeholders are considered both fundamentally crucial and instrumental for effectively gathering, synthesizing, and integrating a wide range of knowledge and diverse perspectives into the energy system model (ESM). This is essential for comprehending and addressing multifaceted societal issues prevalent in contemporary contexts. Although the term “stakeholders” is frequently employed in scholarly discourse and literature, it often lacks a precise and explicit definition to elucidate its meaning in ESM (Miles 2015). Stakeholders may contribute to developing the primary research question or facilitating collaborative understanding and delineation of an issue that requires attention (Lang et al. 2012). In recent years, the approach to stakeholder engagement in energy system modeling has undergone substantial development. The focus has shifted from merely collecting data to cultivating meaningful engagement processes that actively incorporate stakeholders into decision-making. This evolution underscores the growing recognition of the importance of social and political feasibility in energy planning, as highlighted in this review (McGookin et al. 2021). The necessity for consensus-building and collaborative processes has become a priority, signifying a shift towards more inclusive and participatory collaborative practices in energy system modeling (Eker et al. 2017).

The integration of storytelling and simulation combines narrative techniques with modeling to effectively engage stakeholders in understanding complex systems, such as energy systems. This approach enables the examination of various scenarios through storytelling, thereby rendering the technical aspects of modeling more relatable and accessible (Krumm et al. 2022). Andersen et al. (2021) identified five principal categories of stakeholders that play pivotal roles in performing diverse functions in energy system models (ESMs), as shown in Table 1.

Table 1. Overview of stakeholder categories

Tabela 1. Przegląd kategorii interesariuszy

Type of stakeholders	Examples	Role
Experts	Experts from academia, industry, public administration, NGOs, and grassroots organisations.	Provide expertise on the topic, contributing to developing and refining models and scenarios.
Stakeholder representative	Organisational representatives, policymakers, and end-users.	Offers diverse perspectives from organisations or groups, ensuring that the models reflect diverse interests and priorities.
Personal stakeholders	Energy consumers, community advocates, business owners, and residents.	Share personal insights and experiences, which can inform the qualitative aspects of scenario development.
Remarkable people	Energy innovators, environmental activists, and community leaders.	Introduce diverse perspectives and innovative ideas to the scenario planning process, potentially challenging conventional approaches.
Citizens	Local community members, public, youth, and student groups.	Play a pivotal role in developing scenarios by providing localised perspectives and knowledge that can inform energy-related strategies.

Source: Andersen et al. 2021.

Numerous approaches have been developed to classify levels of participation in stakeholder engagement. Consistent with research by other academics (Rowe and Frewer 2005; Trutnevyte and Stauffacher 2012), three distinct aspects of participation approaches were articulated, considering the dissemination of information throughout the process of stakeholder engagement. It is worth noting that Trutnevyte's concept of "information flow" is a widely recognized approach for classifying stakeholder participation in energy research projects. A comparative analysis of these three approaches is presented in Table 2, which elucidates their distinctions in terms of communication methodologies, participation levels, influence on decision-making processes, and overall effects.

Table 2. Key aspects of information, consultation, and collaboration approaches

Tabela 2. Kluczowe aspekty podejścia do informacji, konsultacji i współpracy

Aspects	Information	Consultation	Collaboration
Communication	(1) One-way flow of information (2) Aimed at raising awareness or educating	(1) Two-way communication, allowing feedback (2) Stakeholders express opinions through surveys, interviews, or workshops	(1) Ongoing dialogue and interaction (2) Flexible and adaptive to stakeholder needs
Participation	(1) Limited to receiving information (2) No active engagement or feedback	(1) Advisory role with feedback opportunities (2) Influence on certain aspects of the modelling process	(1) Active involvement in research design and coordination (2) Co-production of outputs and a significant role throughout the process
Decision-making impact	(1) No influence on decisions or outcomes	(1) Limited impact, as input shapes modelling but not research objectives	(1) Substantial impact, allowing changes in research design and objectives
Outcomes	(1) Increased awareness or understanding (2) No direct impact on research or policy decisions	(1) More informed and potentially accepted modelling results (2) Does not fundamentally alter research direction	(1) Comprehensive solutions reflecting diverse perspectives and needs (2) Better alignment with public concerns and preferences

Source: McGookin et al. 2021; McGookin et al. 2024; Trutnevyte and Stauffacher 2012.

2.1.1. Information approach

Unidirectional communication involves scholars disseminating their findings to stakeholders through various means. These include initial presentations of data, the distribution of fact sheets, the creation of informative posters, the provision of fundamental information, and the description of current energy scenarios (McGookin et al. 2021; Trutnevyte et al. 2019). This mode of involvement inherently limits the extent to which stakeholders can contribute, effectively preventing them from substantially shaping the results of ongoing research.

2.1.2. Consultation approach

Two-way communication, involving the active participation of diverse stakeholders who share their distinct perspectives and insights through various means, such as surveys, interviews, and group workshops, is crucial in shaping the overall research landscape (McGookin et al. 2024). Although stakeholders can exert considerable influence on the research outcomes through their inputs and responses, it is essential to recognize that their involvement does not extend to modifying or redefining core research aims or objectives, which remain firmly established within the research framework. This distinction underscores the value of stakeholder contributions in enhancing research findings while simultaneously preserving the integrity and consistency of the original research goals that guide the investigation.

2.1.3. Collaboration approach

Bidirectional dialogue facilitates the collaborative influence of researchers and stakeholders on research objectives. The participants were engaged in the project's inception. Through active participation, they collaborated to develop energy scenarios and contributed to shaping the project outcomes. However, limited research has been conducted on robust collaborative approaches. A notable example is the study in Ref. (Venturini et al. 2019) demonstrated a strong collaborative approach by integrating multidisciplinary expertise, engaging with participatory methods, and fostering iterative revisions and feedback throughout the research process.

2.2. SWOT analysis

A SWOT analysis can provide a comprehensive view of how stakeholder engagement has evolved in energy system modeling. Engaging stakeholders enables a more informed decision-making process, as diverse perspectives can lead to a deeper understanding and greater acceptance of energy policies. A review by McGookin et al. (2021) indicates that stakeholder engagement can significantly inform future energy system configurations. The SWOT analysis is essential for effective strategic planning in energy systems (Trutnevyte and Stauffacher, 2012). This analytical tool enables researchers to determine the most efficacious approach for the various stages of an energy project. For instance, although unidirectional communication may be suitable for disseminating results, it may not adequately engage practitioners. Typically, modelers and researchers interact with the public through the dissemination of information and research. A SWOT analysis can be employed to identify methods for enhancing stakeholder participation. For example, collaboration offers opportunities for mutual learning and commitment to implement ambitious energy goals. Different engagement strategies are required for various phases of energy projects. By implementing SWOT analysis, strategies can be developed to effectively address challenges, such as stakeholder fatigue and the influence of vocal interest groups. This method ensures a more balanced and inclusive process involving stakeholders in ESM (Trutnevyte and Stauffacher 2012; Uwasu et al. 2020).

The SWOT analysis examining stakeholder involvement strategies in ESM provides valuable insights into the strengths, weaknesses, opportunities, and threats associated with various engagements, as depicted in Figure 3. Through a systematic evaluation of each approach, SWOT analysis facilitates informed decision-making. This process ensures that engagement strategies meet technical criteria and align with broader societal objectives, resulting in more equitable and comprehensive outcomes.

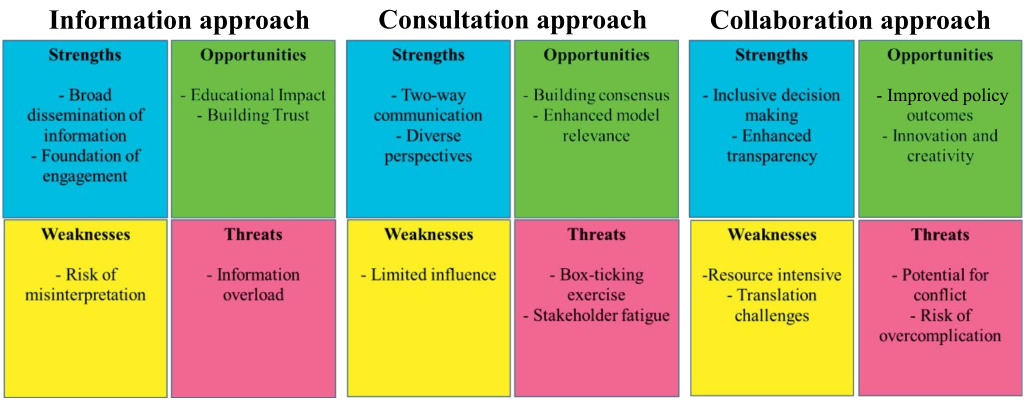

Fig. 3. SWOT analysis of stakeholder engagement strategies

Rys. 3. Analiza SWOT strategii angażowania interesariuszy

2.2.1. Internal factors of information

The information approach promotes accountability and fosters public trust in the modeling process by disseminating information to a broad audience. A well-informed public is more likely to support and have confidence in their ongoing activities and decisions (Xexakis et al. 2020). The dissemination of information constitutes a crucial initial step in stakeholder engagement. Table 3 illustrates the dissemination of information to stakeholders in various studies. Steinberger et al. (2020) highlight that an informative process is fundamental for enabling citizens to make informed decisions. This approach aimed to address knowledge deficits, rectify misconceptions, and expose participants to diverse perspectives. A significant advantage of this information-based approach is its ability to align citizens' preferences closely with their intrinsic values. This approach establishes a foundation for more comprehensive consultation and collaboration by ensuring that all parties are cognisant of the fundamental facts and assumptions underlying the modeling process.

The absence of dialogic opportunities may result in stakeholders misinterpreting the information provided, leading to misconceptions regarding the energy system planning procedure and its outcomes. A significant challenge in interpretation can arise when stakeholders have differing views on the meaning of key driving forces. This phenomenon was exemplified in scenario planning for the Danish transport sector, where the driving force, "Infrastructure", was conceptualized diversely by different parties (Venturini et al. 2019). The interpretations ranged from cycling paths to the expansion of roadways. Such disparities in comprehension can result in discrepancies and misalignment during the development of scenarios, as stakeholders may emphasize different elements based on their interpretations.

Table 3. Overview of information dissemination to stakeholders

Tabela 3. Przegląd rozpowszechniania informacji wśród interesariuszy

Year	Ref.	Information dissemination to stakeholders
2011	Trutnevyte et al. 2011	Information on Urnäsch's commitment to energy efficiency and the "Energiestadt" label was disseminated.
2016	Zivkovic et al. 2016	Stakeholders were informed about the potential of renewable resources in the Niš region, which includes resources from forests, agriculture, and waste.
2017	Demski et al. 2017	The my2050 tool was used to engage the public in exploring their visions and preferences for energy transitions at the national level.
2017	Flacke and De Boer 2017	The COLLAGE tool was used to increase awareness. Stakeholders learned about the limitations and potential of different renewable energy solutions during workshops.
2018	Thomas et al. 2018	Stakeholders were informed about the research on public opinion fluctuations regarding energy issues such as nuclear power and renewable energy.
2018	Volken et al. 2018	The study utilised factsheets to provide stakeholders with brief lay summaries about individual electricity technologies and their environmental impacts.
2023	Holzer et al. 2023	Stakeholders, specifically school pupils, were engaged through workshops using an interactive tool called the Riskmeter. This tool allowed them to create their preferred Swiss electricity supply scenario for 2035, considering technology and energy resource constraints.

2.2.2. External factors of information

The dissemination of information effectively provides an opportunity to elucidate complex energy systems and modeling processes to stakeholders, potentially facilitating their increased participation in future consultations and collaborations. Steinberger et al. (2020) presented participants with concise posters that delineated various electricity technologies to provide a brief synopsis of Switzerland's current situation. Transparent and effective communication can build trust among stakeholders as they observe the openness of the process and remain informed of progress and decisions. This study (Mayer et al. 2014) addressed misconceptions by explicitly addressing prevalent misunderstandings and knowledge gaps, such as the erroneous belief that nuclear facilities generate carbon dioxide (CO_2). This proactive approach to mitigating misinformation fosters trust by demonstrating a commitment to providing accurate and comprehensive information.

There is a potential risk of overwhelming stakeholders with excess information, which may lead to disengagement or confusion, particularly when addressing highly technical or complex subject matter. The challenge of information overload is significant because individuals may be inundated by an abundance of data. This phenomenon may induce cognitive dissonance, potentially confusing the primary message, and lead to a significant level of indifference or detachment from the presented information. To illustrate: in ref. (Volken et al. 2018), participants were provided with comprehensive fact sheets detailing various impacts, including climate change, local air pollution, and resource utilization. The magnitude and complexity of this information could potentially overwhelm participants, impeding their ability to process and retain all particulars.

2.2.3. Internal factors of consultation

The consultation approach facilitates bidirectional communication, enabling stakeholders to articulate their perspectives and potentially influence the modeling process and its outcomes. However, this approach does not permit modifications to the research questions or objectives (Andersen et al. 2021; McGookin et al. 2021). In this approach, stakeholders, including community members, are actively engaged in the discourse on renewable energy projects, providing an opportunity to express their concerns, preferences, and recommendations. For instance, during workshops in Enschede, the COLLAGE tool facilitates bilateral dialogue by enabling participants to visualize and deliberate on various renewable energy scenarios (Flacke and De Boer 2017). This tool not only disseminates information to stakeholders but also allows them to contribute their ideas and observe the immediate effects of their suggestions on the planning process. The consultation approach facilitates the collection of diverse viewpoints through stakeholder engagement via surveys, interviews, or workshops, thereby enhancing the relevance of modeling results. These techniques actively involve a broad range of stakeholders, fostering a sense of value (McGookin et al. 2024) and increasing support for ongoing research (Eker et al. 2017). This reveals diverse preferences for renewable energy, with some stakeholders favoring solar energy and others expressing mixed sentiments about wind energy (Flacke and De Boer 2017), thus highlighting the necessity to consider various opinions in energy modeling and planning.

While stakeholders may influence the modeling process and its outcomes, they are unable to affect the research questions or aims, which can potentially limit the extent of their involvement (McGookin et al. 2024). The consultation approach often involves stakeholder engagement through questionnaires, individual interviews, or group discussions. While these techniques facilitate bidirectional communication, they generally limit participants to influencing the study's outcomes rather than their initial questions or objectives. This approach constrains the extent to which stakeholders can direct their overall research trajectory.

2.2.4. External factors of consultation

Consultation can facilitate consensus among stakeholders regarding optimal approaches, fostering a sense of ownership and commitment to the outcomes. This study (Zivkovic et al. 2016) employed a participatory approach to ensure continuous stakeholder involvement throughout the process. To address real-world challenges more effectively, energy system models (ESMs) can be enhanced by incorporating stakeholder feedback, which potentially exerts a significant influence on policymaking. The stakeholders examined the initial scenarios to verify their alignment with the project's overall objectives (Andersen et al. 2021). This validation process enhances the reliability and credibility of the scenarios, thus augmenting the relevance of the models utilized in scenario planning. In projects such as MedAction, MontanAqua, SCENES, and CLIMSAVE, stakeholders are involved in developing qualitative scenarios and linking them to the quantitative models (Kok et al. 2014; Patel et al. 2007; Schneider and Rist 2013). This integration of stakeholder input into model development ensures that the models are relevant to real-world situations and stakeholder requirements.

The consultation process risks becoming a superficial exercise, wherein modelers create an appearance of stakeholder involvement without substantively incorporating their input. As noted by McGookin et al. (2021), the majority of engagement instances are limited to information extraction, with participants not influencing the formulation of research questions or objectives. Such an approach may result in a nominal engagement process that fails to integrate stakeholder perspectives into the modeling work in a meaningful way. Stakeholders may experience fatigue if they perceive that their contributions do not significantly influence the outcomes or decisions. If stakeholders feel that their input is merely a formality and not genuinely considered in the decision-making process, they may become disillusioned and less willing to engage in future consultations (McGookin et al. 2024).

2.2.5. Internal factors of collaboration

Collaborative approaches facilitate the formulation of research objectives and trajectories by engaging stakeholders from the project's inception and ensuring the integration of diverse perspectives into the decision-making process (McGookin et al. 2024). In the domain of energy systems modeling, collaborative approaches facilitate the incorporation of diverse viewpoints, encompassing those of technical experts, social scientists, and non-academic participants, such as stakeholders and members of the public. This multifaceted input ensures that decision-making processes are more inclusive, considering a broad spectrum of opinions and expertise and resulting in more comprehensive and balanced outcomes. The involvement of stakeholders in the decision-making process across different studies is presented in Table 4.

Engaging in collaborative approaches typically requires a greater investment of time, resources, and effort than other forms of interaction, such as communicative or consultative approaches. Converting collaborative discussions and decisions into formal written documents

Table 4. The role of stakeholders in the collaborative decision-making process

Tabela 4. Rola interesariuszy w procesie wspólnego podejmowania decyzji

Year	Ref.	Role of stakeholders in the decision-making process
2014	Bessette et al. 2014	In the formulation of energy strategies for Michigan State University (MSU), key stakeholders assumed a pivotal role in the decision-making process. This collaborative approach constituted a crucial component of a broader sustainability initiative, which aimed to establish a comprehensive, long-term plan for the university's power generation infrastructure.
2015	Bertsch and Fichtner 2015	In the decision-making process within the energy sector, public acceptance is a critical factor, and stakeholders play a significant role in its attainment. Through stakeholder engagement, organisations effectively address societal concerns and preferences, thereby facilitating consensus and acceptance of energy-related decisions within the community.
2016	Vaidya and Mayer 2016	Stakeholders included local landowners, farmers, township supervisors, timberland management companies, venture capitalists, governmental organisations, and local interest groups. This diverse representation ensures that various perspectives and interests are considered in the decision-making process.
2018	McKenna et al. 2018	Workshops incorporating energy modelling and multi-criteria decision analysis (MCDA) were employed to engage stakeholders. These sessions serve a crucial function of collaborating with local communities to formulate energy concepts, thereby ensuring an inclusive decision-making process that considers the perspectives of diverse stakeholders.
2020	Uwasu et al. 2020	The concept of imaginary future generations was introduced to incorporate the perspectives of future stakeholders who are not present. This involves current stakeholders taking on roles that represent future generations, ensuring that their rights and interests are considered in present-day decision-making.

presents significant challenges (Eker et al. 2017). A substantial impediment to the transformation of narrative scenarios into quantitative models is that the translated parameters frequently fail to adequately capture the complexity of qualitative storylines (Venturini et al. 2019).

2.2.6. External factors of collaboration

Collaborative efforts incorporating diverse perspectives can yield more balanced policy decisions that accurately reflect societal needs and preferences. Collaboration facilitates the consideration of regional variations in citizen preferences, potentially resulting in tailored and effective policies. Ref. (Dubois et al. 2019) identified contextual disparities between Geneva and Zurich, indicating that regional cooperation can address specific local requirements and enhance policy acceptance. Moreover, this study (Xexakis and Trutnevyte 2022) suggests that model-based scenarios often fail to reflect public aspirations for more extensive decarbonization and denuclearisation. By aligning scenarios with public preferences, policymakers can ensure that policies are ambitious and consistent with societal objectives, ultimately leading to improved outcomes. Collaborative approaches involving multiple stakeholders, including citizens, can explore innovative and creative solutions for energy planning (Xexakis and Trutnevyte 2022). By integrating diverse perspectives, modelers can explore unconventional pathways and technologies that cannot be considered in traditional model-based scenarios. This can result in more creative and efficacious strategies for achieving the energy transition goals.

Diverse stakeholder groups may possess conflicting interests, potentially leading to disagreements and impeding the decision-making process. Bertsch and Fichtner (2015) emphasize the significance of public acceptance in decision-making processes. Conflicts may arise when infrastructure projects, such as grid expansions, encounter opposition from the public due to environmental concerns or other factors. This opposition could potentially compromise the collaborative approach by creating a dichotomy between technical experts and the public. The participation of numerous stakeholders often complicates the process, hindering the achievement of clear outcomes or consensus. In collaborative endeavors, particularly those involving multiple parties, there is the potential for unnecessary complexity arising from the varied perspectives and aspirations each participant brings to the table (Alvial-Palavicino et al. 2011). This diversity of viewpoints can result in intricate negotiation and decision-making processes, potentially complicating the project rather than simplifying it.

3. Discussion

The SWOT analysis highlights the dynamic nature of stakeholder engagement in energy system modeling and underscores the need for continued evolution in practices to enhance public trust and model effectiveness. The transition from information to consultation to collaboration can be conceptualized as a continuum encompassing a range of diverse activities. Although information and consultation are crucial, they often involve stakeholders at limited stages of the energy planning process, such as the beginning or end (McGookin et al. 2024). This can diminish the impact of stakeholders on the decision-making procedure and the final model outcomes.

The consultation approach typically involves gathering input from stakeholders through methods such as questionnaires or group sessions (Andersen et al. 2021). Nevertheless, it may not integrate stakeholders into decision-making processes as comprehensively as collaborative approaches do. In Germany's Energiewende, consultation was the primary method employed. This approach encompasses public meetings and hearings wherein citizens and interested parties can express their opinions and provide feedback on energy policies.

Collaboration involves active stakeholder participation throughout the modeling process, from the initial stages to final decision-making (McGookin et al. 2021). This approach ensures that stakeholders significantly influence the model's development and outcomes by aligning them with their requirements and preferences. Collaborative approaches enable the incorporation of diverse perspectives and treat them as valuable contributions rather than impediments. This approach requires skilled facilitators to effectively manage divergent viewpoints, ensuring that all stakeholder inputs are considered (McGookin et al. 2024). In Poland, the process of stakeholder participation in the Energy Policy until 2040 (PEP2040) is meticulously structured to include a diverse range of stakeholders. This encompasses governmental and self-government administrative bodies, various governmental institutions, and businesses within the fuel and energy sector, thereby ensuring the incorporation of multiple perspectives into the energy transition. The policy underscores the importance of a just transition, emphasizing fair and inclusive stakeholder engagement, particularly among vulnerable social groups. Continuous monitoring of stakeholder involvement is crucial for assessing the effectiveness of participation strategies and evaluating the extent to which different entities fulfill their roles in the energy transition. Overall, stakeholder participation in Poland's energy policy is characterized by collaboration among various entities, collectively striving to achieve the objectives of PEP2040, which aims to facilitate a fair and effective energy transition for the nation (Ministry of Climate and Environment 2021). In Denmark, energy planning frequently employs participatory methods that actively involve stakeholders, including members of the public, in the development of scenarios and decision-making processes. This is exemplified in the Danish transport sector, where representatives from both public and private organizations collaborate to create transport scenarios and optimize policies within an integrated energy system framework (Venturini et al. 2019).

Of the 60 reviews examined, 34 studies focused on disseminating knowledge using an informational approach. The primary methods involve stakeholders in energy modeling centers sharing information and communicating research outcomes (McGookin et al. 2024). Although the informational approach is practical in disseminating knowledge, its unidirectional nature imposes certain limitations. Nonetheless, this approach serves as a foundation for more interactive engagement strategies, such as soliciting input and fostering collaboration. By initially educating stakeholders, the informational method establishes a basis for more extensive participation and feedback in the subsequent phases of the modeling process.

The two-way dialogue constitutes a significant advantage of the consultation approach. However, this approach may encounter difficulties in effectively incorporating stakeholder input because of the limited influence of stakeholders. There exists a possibility that these processes could become superficial or perfunctory, merely serving as 'box–ticking' exercises rather than genuinely integrating stakeholder perspectives into the modeling process. The consultation approach was constrained by its iterative nature. Merely soliciting stakeholder views without incorporating feedback into the modeling process does not constitute meaningful involvement. However, it is crucial that stakeholders recognize the contribution of their input to the research and modeling outcomes (Uwasu et al. 2020). In the absence of such recognition, stakeholders may become disillusioned with the process, potentially losing trust and interest in participating in energy system modeling – a phenomenon often referred to as stakeholder fatigue (Clark 2008).

Of the 60 reviews, 23 studies concentrated on collaborative methods combined with information and consultation strategies. Nevertheless, five studies exhibited strong collaborative approaches. The collaborative approach, although resource-intensive, presents opportunities for improved knowledge sharing and continuous stakeholder engagement, potentially leading to more impactful policy outcomes. This approach enables the integration of diverse perspectives, enriching the modeling process by addressing the concerns and requirements of various stakeholders and ultimately producing more comprehensive solutions. Stakeholders actively contribute to the co-creation of narratives that underpin the simulations (Amin et al. 2024). Their diverse perspectives and experiences enrich the scenarios, ensuring that they accurately reflect the complexities and concerns of the real world (Trutnevyte 2016). This collaborative approach enhances the relevance of the modeling effort.

However, each approach has limitations. Information strategy risks misinterpretation and limited engagement. Consultation may become superficial if stakeholder inputs are not genuinely incorporated (Voinov and Bousquet 2010). Collaboration, despite offering the most comprehensive engagement, can be resource-intensive and may precipitate conflicts due to divergent stakeholder interests (Schmid et al. 2017). To enhance the efficacy of stakeholder involvement in energy system modeling, it is essential to address recognized challenges such as stakeholder fatigue and credibility concerns (Clark 2008). Implement collaborative approaches that involve stakeholders throughout the modeling process, from the initial stages to decision-making, ensuring that their contributions are effectively incorporated into the outcomes. Establish clear and transparent communication channels to keep stakeholders informed and engaged, foster trust, and mitigate engagement fatigue by rendering the process meaningful and transparent.

The modeling community is experiencing a significant shift towards open and transparent collaborative approaches (DeCarolis et al. 2020; Xexakis and Trutnevyte 2022). It is imperative to explore further the transparent and iterative framework of collaborative approaches to engage a diverse array of stakeholders in energy planning (Amin et al. 2024; Xexakis and Trutnevyte 2022). Subsequent research could focus on developing models that facilitate constructive dialogue and discourse, thereby fostering trust and mutual understanding among stakeholders. The examination of collaborative approaches may provide novel insights into stakeholder engagement. This encompasses the investigation of how such approaches can enhance the representativeness and effectiveness of stakeholder participation in energy system modeling.

Conclusions

In conclusion, although the information approach plays a vital role, it often serves as a foundation rather than a comprehensive strategy. Therefore, maintaining stakeholder awareness is imperative. Although the consultation approach is frequently employed, the study (Voinov and Bousquet 2010) cautions against superficial engagement, which may occur if consultation is not substantively incorporated into the modeling process.

Collaboration appears to be the most effective method for incorporating stakeholders into energy system modeling. This approach facilitates a more profound engagement and integration of diverse perspectives, which are essential for developing models that are pertinent, actionable, and aligned with stakeholder requirements. Although informational and consultative approaches are significant, their efficacy is maximized when implemented within a more comprehensive collaborative framework.

To enhance stakeholder engagement in energy system modeling, policymakers should consider implementing integrated strategies that combine consultation and collaboration to achieve a more comprehensive approach. Governmental entities should allocate resources to support community-led energy initiatives, establish online platforms for stakeholder discourse, and ensure transparency in decision-making processes to foster public trust.

The Author has no conflicts of interest to declare.

Appendix A

Table 5. Stakeholder engagement approaches in energy system modelling and planning

Tabela 5. Podejścia dotyczące zaangażowania interesariuszy w modelowaniu i planowaniu systemów energetycznych

Sl.	Year	Ref.	Stakeholder engagement level		
			information	consultation	collaboration
1.	2007	McDowall and Eames 2007		✓	
2.	2007	Madlener et al. 2007			✓
3.	2007	Terrados et al. 2007		✓	✓
4.	2009	Kowalski et al. 2009	✓	✓	✓
5.	2010	Schmitt Olabisi et al. 2010	✓	✓	✓
6.	2010	Salerno et al. 2010	✓	✓	✓
7.	2011	Trutnevyte et al. 2011	✓	✓	✓
8.	2011	Atwell et al. 2011		✓	✓
9.	2011	Alvial-Palavicino et al. 2011	✓	✓	✓
10.	2012	Schmid and Knopf 2012		✓	✓
11.	2012	McDowall 2012		✓	
12.	2012	Wilkens and Schmuck 2012	✓	✓	✓
13.	2014	Düsphol et al. 2014			✓
14.	2014	Bessette et al. 2014	✓	✓	✓
15.	2014	Mayer et al. 2014	✓	✓	
16.	2015	Fortes et al. 2015		✓	
17.	2015	Mathy et al. 2015		✓	✓
18.	2015	Bertsch and Fichtner 2015		✓	✓

Sl.	Year	Ref.	Stakeholder engagement level		
			information	consultation	collaboration
19.	2015	AlSabbagh et al. 2015		✓	
20.	2016	Vaidya and Mayer 2016	✓	✓	✓
21.	2016	Höltinger et al. 2016			✓
22.	2016	Macmillan et al. 2016			✓
23.	2016	Krzywoszynska et al. 2016	✓	✓	✓
24.	2016	Foran et al. 2016	✓	✓	✓
25.	2016	Zivkovic et al. 2016	✓	✓	✓
26.	2017	Demski et al. 2017	✓	✓	
27.	2017	Robertson et al. 2017			✓
28.	2017	Schmid et al. 2017	✓	✓	
29.	2017	Sharmina 2017	✓	✓	
30.	2017	Eker et al. 2017			✓
31.	2017	Dubinsky et al. 2017	✓	✓	✓
32.	2017	den Herder et al. 2017	✓	✓	✓
33.	2017	Busch 2017	✓	✓	✓
34.	2017	Flacke and De Boer 2017	✓	✓	✓
35.	2017	Marinakis et al. 2017	✓	✓	✓
36.	2018	Ernst et al. 2018	✓	✓	✓
37.	2018	Noboa et al. 2018			✓
38.	2018	Volken et al. 2018	✓	✓	
39.	2018	Nabielek et al. 2018	✓	✓	✓
40.	2018	Heaslip and Fahy 2018	✓	✓	✓
41.	2018	Giannouli et al. 2018	✓	✓	✓
42.	2018	McKenna et al. 2018	✓	✓	✓
43.	2018	Chapman and Pambudi 2018		✓	
44.	2018	Thomas et al. 2018	✓	✓	
45.	2018	Soria-Lara and Banister 2018			✓
46.	2018	Jeong 2018		✓	✓
47.	2019	Schinko et al. 2019			✓
48.	2019	Venturini et al. 2019			✓
49.	2019	Vargas et al. 2019	✓	✓	✓
50.	2019	Zelt et al. 2019			✓
51.	2019	Simoes et al. 2019	✓	✓	✓
52.	2019	Bernardo and D'Alessandro 2019	✓	✓	✓
53.	2020	Droste-Franke et al. 2020			✓
54.	2020	Steinberger et al. 2020		✓	
55.	2020	Uwasu et al. 2020	✓	✓	✓

Sl.	Year	Ref.	Stakeholder engagement level		
			information	consultation	collaboration
56.	2020	Xexakis et al. 2020	✓	✓	
57.	2020	Michas et al. 2020	✓	✓	
58.	2020	Sharma et al. 2020		✓	✓
59.	2023	Holzer et al. 2023	✓	✓	
60.	2024	Davidsdottir et al. 2024		✓	✓

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Riasad Amin

Badanie zaangażowania interesariuszy w modelowanie i planowanie systemów energetycznych: przegląd systematyczny z wykorzystaniem analizy SWOT

Streszczenie

Globalna transformacja energetyczna w kierunku zrównoważonego rozwoju wymaga ram, które integrują aspekty techniczne, ekonomiczne i społeczne. Zaangażowanie interesariuszy ma kluczowe znaczenie w modelowaniu i planowaniu systemów energetycznych. Niniejsze studium stanowi przegląd systematyczny technik angażowania interesariuszy w modelowanie systemów energetycznych poprzez zastosowanie analizy SWOT do oceny strategii zaangażowania. Ma ono na celu zbadanie skuteczności różnych podejść do udziału interesariuszy oraz metod włączania interesariuszy w proces podejmowania decyzji w celu zwiększenia zaufania publicznego i akceptacji modeli transformacji energetycznej. W badaniu zidentyfikowano i przeanalizowano trzy podstawowe podejścia do zaangażowania: informacyjne, konsultacyjne i oparte na współpracy. Przeprowadzono analizę SWOT w celu oceny mocnych i słabych stron każdego z tych podejść. Podejście informacyjne skutecznie rozpowszechnia wiedzę, ale jest ograniczone ze względu na swój jednokierunkowy charakter. Podejście konsultacyjne ułatwia dwustronny dialog, ale może powodować trudności z efektywnym włączeniem opinii interesariuszy. Podejście oparte na współpracy, wymagające dużych nakładów zasobów, oferuje możliwości lepszej wymiany wiedzy i ciągłego zaangażowania interesariuszy. W ramach badania stwierdzono, że podejścia informacyjne i konsultacyjne są najskuteczniejsze, gdy są wykorzystywane jako elementy szerszych ram współpracy. Wyniki te stanowią wkład w bazę wiedzy dla modelarzy, decydentów i badaczy zajmujących się planowaniem transformacji energetycznej oraz oferują cenne spostrzeżenia dotyczące opracowywania bardziej sprawiedliwych społecznie strategii transformacji energetycznej.

Słowa kluczowe: zaangażowanie interesariuszy, analiza SWOT, modelowanie systemów energetycznych, zrównoważona transformacja energetyczna, wspólne podejmowanie decyzji