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Exploring the energy informatics and energy citizenship domains: a systematic literature review

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Abstract

To effectively address the challenges posed by the increasing share of the energy sector in global greenhouse effects, the domains of energy informatics and energy citizenship play a critical role. Energy informatics aims at using information systems and channels to reduce energy consumption. However, there is a realization that the challenges posed by global greenhouse effects cannot be catered to alone by the energy information systems. Therefore, there is a need for engaging human inhabitants to actively engage toward more sustainable means (i.e., energy citizenship) thus reducing the energy sector's share in the global greenhouse effect. This paper presents a systematic literature review (SLR) after analysis of (n = 115) articles on the topic to identify (i) the themes considered in energy informatics and energy citizenship domains, and (ii) the interconnection between energy informatics and energy citizenship domains, (iii) energy information needs among stakeholders which establish a clear interconnect with energy citizenship. These identified themes and their interconnections are critical for energy researchers, policymakers, and energy businesses to identify relevant research topics, identify energy consumers' needs, and create just energy transition policies. The paper additionally summarizes the gaps in the state of the art by mentioning the open research questions that arise due to the identified interconnection between energy informatics and energy citizenship.

Keywords: Energy informatics, Energy citizenship, Energy communities, Energy policy, Energy transition

Introduction

Global warming poses a serious challenge to the planet Earth and its inhabitants. To address this challenge, 196 world leaders reached a binding agreement [The Paris Climate Agreement 2015 (Teske 2019)] that aims to limit the rise of average global temperatures by 1.5 °C above the pre-industrial level. Other common goals include climate resilience and sustainable energy transition (Teske 2019; Dinerstein et al. 2019). Notably, the combustion of carbon gases and fuels for energy production has a significant share of global greenhouse gas production. The global greenhouse directly impacts rising earth temperatures (Akaev and Davydova 2021).

The share of the energy sector in global greenhouse gas is estimated differently. For example, global energy-related CO_2 emissions measured in Gigatons (Gt) have increased drastically from 20.5 Gt to 33.0 Gt in a span of 30 years (1991–2021) (IEA https://www.iea.org/data-and-statistics/charts/global-energy-related-co2-emissions-1990-2021). Alternatively, energy is estimated to contribute more than 73% of global carbon emissions. These emissions include 'energy used in buildings (17.5%)', 'energy used in transport (16.2%)', 'energy used in industry (24.2%)', and other smaller sources, which makes it important to focus on these sectors and try reducing this contribution to global greenhouse gases (Ritchie et al. 2022).

While this scenario calls for multi-faceted efforts such as gaining the focus of policymakers and transitioning to green means of energy production for businesses and transport, it is also important to take steps towards empowering the citizens and facilitating the transition to sustainable societies. This requires more research funding (European Commission 2022), a stable energy business model that allows for a profitable enterprise (Fernández-González et al. 2020; Solaun and Cerdá 2020; Hänsel et al. 2020), and educating young children as well as the adult population about the importance of green energy (Oliver and Adkins 2020; Bordin et al. 2021). Researchers have seen that citizens and communities can transition from lower engagement levels such as being 'unaware' concerning energy sustainability towards transitioning to being 'aware' and gradually transitioning to higher engagement levels such as being involved, active, and advocating (Devine-Wright 2012; Hamann et al. 2022; Koning et al. 2020). There is a cross-cutting mix of influencing factors such as legal, economic psychological (Devine-Wright 2012; Hamann et al. 2022), technological, geographical, and sociological aspects (Veelen and Horst 2018; Koning et al. 2020) that govern civic engagement for a sustainable society, one of these influencing factors is energy information (Lizana et al. 2021; Huh et al. 2019).

Energy informatics (EI) focuses on increasing the energy efficiency of energy systems by designing and implementing systems that can extract and analyze data from different energy systems using the skillset and know-how of information systems (Kumar and Bhattacharjee 2018; Watson et al. 2010). In energy informatics, the collection and analysis of energy data are carried out to increase energy efficiency in energy distribution and consumption networks (Watson et al. 2010). It has been seen that providing the end user with energy consumption-related data does influence energy consumption behavior, but such behavior also depends on other societal factors and social dynamics (Yim 2011a). Researchers have long advocated that community-based initiatives could more significantly influence energy behavior by introducing a pro-environmental social norm in the community and such programs are successful if they are part of a wider program with clear objectives, such as reducing carbon footprint or reducing energy consumption needs (Barbu et al. 2013). This makes EI critical in the context of Community Transition Pathways (CTP), which are routes that support communities to transition between different engagement levels (Lizana et al. 2021; Huh et al. 2019; Koning et al. 2020).

There is a need to transition to more sustainable energy solutions while at the same time being more efficient in the use of carbon-based energy sources. This requires action from high-level officials, policymakers, and the public. Active engagement toward sustainable societies, especially by the public, is referred to as Energy

Citizenship (EC) (Devine-Wright 2012; Hamann et al. 2022; Li et al. 2021). Energy informatics refers to collecting and using data and information from energy systems to improve energy efficiency. Providing end users with information produced from energy systems, such as consumption data on their bill or by a smart meter, may influence energy consumption, but this may depend on other societal factors and social dynamics (Boamah and Rothfuß 2020). Researchers have also shown that community-based, participatory initiatives have an important role in influencing energy behavior through motivation or nudging as well as through providing new perspectives about energy usage through energy information (Zyl-Bulitta et al. 2019; Ringholm 2022; Wahlund and Palm 2022; Veelen and Horst 2018; Koning et al. 2020). This leads to the question of whether energy informatics reaches its full potential in supporting all different types of stakeholders who might benefit from it, especially in supporting individuals and communities for active energy citizenship.

However, critics argue that the energy citizenship concept puts undue pressure on the individual to be an ideal citizen and suggest that probably communal aspects of energy citizenship should be explored more, including energy literacy, energy democracy, and energy communities (Devine-Wright 2012; Hamann et al. 2022; Ryghaug et al. 2018; Geerts et al. 2022). In this context, catering energy information is required to suit different energy information needs. This necessitated the need to understand the state-of-the-art in both the domains discussed above and identify the existing research themes to understand the scope of the research area, identify the current research focus, and find common links between EI and EC for further exploration. In view of the discussion above, this article attempts to identify essential attributes and themes associated with energy informatics and energy citizenship domains and the interconnect between them. To do so, a Systematic Literature Review (SLR) was conducted while considering the following research questions:

RQ1—What are the main themes explored in the domain of Energy Informatics?
RQ2–What are the main themes explored in the domain of Energy Citizenship?
RQ3—How do energy informatics and energy citizenship interconnect?

This paper brings to its readers the outcomes of the SLR process. Briefly, the SLR enabled identifying (1) current research themes in the domain of Energy Informatics, (2) current research themes in the domain of energy citizenship, and (3) the relationship between energy informatics and energy citizenship. The finding of the SLR can aid policymakers in designing better energy policies and may help energy companies to realize that they need to make additional efforts to understand the information needs of the consumer in order to reach them more effectively and take additional steps towards achieving standardization, or at least providing new knowledge to inform standardization of energy services and energy information to achieve energy goals.

Structure of the paper: The rest of the paper is organized as follows. The background section presents the background of the study field. The methodology section presents the methodology adopted for undertaking the SLR process. The Result section presents the results of the study. The Discussion section presents the discussion and open research issues that emerge after the analysis of the state of the art, and finally, the Conclusion section concludes the paper.

Background

Energy systems, which include energy extraction or generation, energy transmission, energy business, energy usage, energy storage, and energy analytics provide a way to deliver energy services to end users (Huang et al. 2017). These systems have over the years been increasingly dependent on Information Systems across the energy chain, starting from energy exploration and as we move down the chain towards energy infrastructure, energy generation, energy transmission, energy distribution, energy storage, and commercial and residential usage.

Energy informatics is considered a separate subfield of information systems (Watson et al. 2010; Goebel et al. 2014). It is based on the founding theory that energy when combined with informatics could lead to less energy consumption and more energy savings or a transition to green energy (Watson et al. 2010). Similarly, EC is a socio-political approach toward energy transition that involves public participation in energy generation or the adoption of renewable energy consumption (Devine-Wright 2012; Hamann et al. 2022).

During the last decade, there has been considerable research and researchers have identified various goals and themes associated with these domains [EI: (Goebel et al. 2014; Sultan and Hilton 2019); EC: (Devine-Wright 2012; Hamann et al. 2022; Wahlund and Palm 2022)]. To better understand the topic, we have identified two possible perspectives to classify the existing research presented in the subsequent sub-sections.

Energy informatics

The primary focus in the field of Energy Informatics has traditionally been to capture high-level granular data about the distribution and consumption of energy with an aim to reduce energy consumption. Energy informatics has two major focus points, namely, (1) knowing how information systems can be used to reduce energy consumption, and (2) what practical solutions can be employed to increase environmental sustainability and align it with ecological goals (Watson et al. 2010).

Furthermore, Watson et al. advocates the need to design practical solutions that advance environmental sustainability, adopting a solution science approach by incorporating fields such as management science, design science, and policy formation. Moreover, it is vital to produce an integrated solution that considers both the supply and demand sides of the energy. To serve this cause, the Energy Informatics framework was proposed, which envisages that information systems should be the common interface between the electricity supply side and the electricity demand side to ensure a cohesive solution to ecological goals that are common for all stakeholders such as consumers, suppliers, and government. An Energy Information system integrates these elements into a single system (Watson et al. 2010).

When considering the scope of the domain, it is relevant to mention the work by Goebel et al. (2014). The authors suggested that Energy Informatics has two goals. (1) to increase energy efficiency, and (2) to increase renewable energy supply. These two goals have led to two main themes in EI research. The first one deals with the smart energy-saving system and the second deals with the smart grid. The research in this field is applicable to the transportation system, help reduces energy consumption in commercial, residential, and industrial units, in power systems, and in increasing coverage of renewable energy, electricity market, and energy storage technologies (Goebel et al. 2014).

It is relevant to state an essential component of Energy Informatics is based on elements of Information and Communication Technologies (ICT). ICT helps in better measurement and understanding of user energy consumption and therefore energy systems can react accordingly. In this context, three challenges are important to be considered (Goebel et al. 2014). (1) the first challenge is to collect and store energy-related data, (2) the second is to attribute energy usage to single devices, people, processes, and organizational units, and (3) the third one is to present and contextualize energy data in a way that enables energy savings. These challenges need to be solved using a multi-disciplinary approach (Goebel et al. 2014). For example, event processing systems are needed to process sensor data, a new evaluation of human–computer interfaces is required, new benchmarking schemes need to be developed, efficiency in data retrieval and storage is required along with advanced knowledge about how people and organizations react to various types of information regarding their energy consumption. Also, the long-term success of Energy Information systems depends on individual incentives and behavioral dynamics such as learning and feedback among peers (Goebel et al. 2014).

Furthermore, experts agree that ICT plays a leading role in making the integration of renewable energy into the electric grid possible, which has resulted in a call for smart grids to realize the full potential of flexible loads and enable effective demand-side management in large numbers (Appelrath et al. 2012). EI research on smart grids focuses on how ICT can be used to achieve the manageability of electric loads and to develop control systems that leverage the controllability of decentralized energy suppliers, variable loads, and energy storage systems for the integration of renewable resources into power systems. The goal is to make energy consumption more measurable and controllable by reacting to the fluctuating supply of renewable energy sources by shifting the electric load from times of low supply to times of high supply (Goebel et al. 2014).

Another sub-topic being actively considered in the domain of EI is grid reliability. The nature of energy generation is changing rapidly. There are many new developments in the electric power network along with the incorporation of distributed energy resources such as user-generated power through solar panels, circuits, equipment overloads, etc. are making electric grid reliability research an important topic. The research also advocates including service reliability as the *third goal* of Energy Informatics research and smart grid reliability and resiliency as another research theme of the Energy research framework (Goebel et al. 2014; Sultan and Hilton 2019).

Furthermore, with the advancement of AI and machine learning algorithms, there have been new opportunities in EI specifically relevant to energy data analytics, which can be used for tasks such as predictive load modeling, load balancing, demand forecasting, and energy optimization (Kumar and Bhattacharjee 2018; Huang et al. 2017).

These algorithms are particularly useful in building informatics and are employed to increase the energy efficiency of a building (Lim et al. 2018).

In the domain of EI, while it is important to consider technical perspectives such as optimization, and reduction of transmission losses, it is vital to consider individual and behavioral dynamics associated with the end-user to influence their electricity usage behaviors (Barbu et al. 2013; Sultan and Hilton 2019). In this regard, many researchers have shown that adding energy usage-related data to energy bills brings changes in consumers' energy behavior (Wilhite and Ling 1995). If such feedback is given regularly, it could lead to the thought of investment in efficiency measures, which could act as a motivation to change. However, such behavioral changes are only effective when energy usage information is also used along with incentives. In absence of incentives, behavioral changes fade away (Darby 2006).

Energy citizenship

More recently, the research that focuses on renewable energy research has shifted from individual-based renewable energy interventions to community-based renewable energy interventions. There has been a considerable increase in research related to community energy in the domain of energy informatics (Bauwens et al. 2022). EI researchers are now expanding the domain with the inclusion of concepts like EC, which simply put, is people's right and responsibility for a just and sustainable energy transition (Devine-Wright 2012; Hamann et al. 2022). There is a focus on studying how community dynamics influence energy behavior. It has been reported that energy behaviors are more easily adaptable in a more cohesive and close-knit community (Yim 2011b).

In addition to utilizing the community as a tool for transitioning to a society with distributed energy generation, the big picture of EC focuses on understanding different aspects that could improve the energy citizenship experience for everyone. Therefore, concepts like energy democracy, energy justice, energy equity, energy literacy, and energy poverty are prominently featured in EC literature. The focus here is to make transitioning feasible and accessible to everyone in an equitable manner. For example, some views of energy citizenship focus on materialistic possession this is not necessarily inclusive to everyone because such views do not consider individuals who may not have economic or legal means to participate in renewable energy generation yet may still be successful advocates of sustainable solutions. Another criticism of EC is that it puts the burden of transition on citizens absolving the government and energy companies, who are themselves responsible for the need to transition, from the outcome of transition efforts. Researchers have also observed that some projects at the time of planning talk about concepts of energy justice and resolve to incorporate public needs, however, those commitments are rarely met at the time of project implementation (Devine-Wright 2012; Boamah and Rothfuß 2020; Wahlund and Palm 2022).

EC researchers are also interested in knowing how energy technology and energy citizens interact and how much role energy literacy plays in the successful energy transition (Lizana et al. 2021). Researchers also want to make sure that energy technologies adapt to different energy citizens' needs. This requires transparency in energy data, access to energy systems, and empowerment through policies (Anfinson 2022). Moreover, researchers have focused on understanding the motivation for participation in energy transition and enabling factors and researchers have broadly viewed EC from three different perspectives, namely psychological, economical, and legal. While the psychological aspects focus on what makes people adopt energy citizenship, the economic aspects focus on how to involve the economically poor in the energy transition journey and the legal aspect focuses on the commercial right of citizens to produce and trade energy (Devine-Wright 2012; Hamann et al. 2022).

All these factors point to the critical role of EC in the energy transition journey and different factors that influence the wider adoption of renewable energy and play a crucial role in advancing the concept of energy citizenship by inculcating values from concepts of democracy, learning, community, economics, and technology. The confluence of all these factors along with energy informatics can provide quantifiable energy data, that can then be used to continuously measure energy systems parameters, manage energy communities, optimize energy systems, track the energy demand cycle, manage consumers' expectations, measure the social impact of energy projects and systems objectively and identify best practices for energy transition goals.

Methodology

A Systematic Literature Review (SLR) is a method of scientific investigation or study that is focused on a certain question(s), whose answer is being searched for, using explicitly detailed and pre-defined scientific methods (Kitchenham et al. 2009). In SLR, the goal is to avoid random sampling of scientific literature and avoid introducing biases. To achieve this, many protocols are available (Mohamed Shaffril et al. 2021). This paper has adopted Kitchenham's method that stresses evidence-based research devoid of biases, inspired by medical science as well as sociology. The process adopted for SLR may help advance multiple aspects of research interest such as establishing an efficient way to select the best available research or help facilitate research approaches by identifying existing as well as the latest research gaps and study limitations (Kitchenham et al. 2010). Researchers may have varied reasons to undertake SLR, ranging from summarizing the existing research on a topic to identifying gaps in current research and even proposing a new framework or testing a hypothesis (Keele 2007).

SLR is undertaken in three phases: (1) planning the review, (2) conducting the review, and (3) reporting the review. Initially, the review protocol is decided according to the research questions addressed, and the review is carried out. The next step is to define a search strategy to detect as much relevant literature as possible. In SLR, it is important to document the search strategy so that readers can assess its rigor, completeness, and repeatability. Moreover, inclusion and exclusion criteria need to be explicitly stated including quality criteria (Keele 2007).

A systematic literature review can be defined as a process of secondary study that aims to comprehensively locate and synthesize related research using an organized, transparent, replicable, and well-defined methodology to identify, analyze and interpret all available evidence related to a specific research question in a way that is unbiased and repeatable (Keele 2007; Kitchenham 2012).

Need for the review

EI has been around for more than a decade, and there has been no recent state-of-the-art SLR on themes in EI, even though initial literature has defined the scope of EI and just two research themes. A thorough search via online scientific databases with the keywords *"energy"* and *"informatics"* was conducted. Though there is research to define the scope of EI, no comprehensive SLR would detail the current state of research on this topic. However, there are SLRs on topics such as electric load management (Benetti et al. 2016), household energy efficiency (McAndrew et al. 2021), smart grid (Vakulenko et al. 2021), smart grid authentication approaches (Qasaimeh et al. 2019), Sustainability concerns, and policy implications of urban household consumption (Shittu 2020), which are closely linked to sub-topics in EI. Therefore, SLR was needed to summarize the broader themes in EI research, the involvement of community aspects in EI research themes, and its potential relationship with newer concepts such as energy citizenship.

As a next step, Research Questions (RQ) were formulated. Researchers have suggested that the PICO method is well-suited for framing an SLR question (Khakurel et al. 2018). PICO is inspired by the field of medicine and helps in retrieving the most relevant literature, even though researchers suggest Comparison (C) steps could be removed (Khakurel et al. 2018; Schardt et al. 2007; Davies 2011). In the present context, the Population (P) are end users, Intervention (I) is Energy Information and Outcome (O) is the summary of current themes in EI research, the aspect of community in EI, and its relationship with newer concepts like energy citizenship. With the above structure in mind, three RQs were created, each having a specific rationale to obtain a comprehensive overview of the topic.

RQ1—What are the main themes explored in the domain of Energy Informatics?
RQ2—What are the main themes explored in the domain of Energy Citizenship?
RQ3—How do energy informatics and energy citizenship interconnect?

Selection of literature

The selection of literature is a two-phase process, (1) identification of literature and (2) screening of literature. In the first phase, a list of papers was retrieved from the database using specific keywords or Search Terms (ST). The list of databases considered during this SLR includes:

- *ACM*
- *IEEE*
- *Scopus (Elsevier)*
- *Web of Science*

These databases were selected because of their relevance to the field of study. The STs were identified using the method described in Khakurel et al. (2018). Since there were two broader sets of themes that needed to be identified from two different topics and the relationship between them, it was necessary that two different Search Queries (SQ) be created. The SQs were:

Table 1 Inclusion and Exclusion Criteria

InC 1	The publication discusses topics related to energy informatics or energy citizenship
InC 2	The publication text is available in English
InC 3	The publication discusses information related to informatics, transition, community, sustainability, policy, technology, optimization, management, digitalization, and business
InC 4	The publication has been published in a reputed peer-reviewed journal or conference
ExC 1	Publications that have missing abstracts/meta-data
ExC 2	Publications whose full-text version is not available or are not accessible
ExC 3	Publications that are not published within the range of 2018–2022

(1) “Energy” AND “Informatics” OR” Energy Informatics”
(2) “Energy” AND “Citizenship” OR “Energy Citizenship”

The search output was subjected to screening in two phases, (1) based on inclusion criteria (InC) and exclusion criteria (ExC) as mentioned in Table 1, and (2) after reading the titles and abstract. The InC and ExC were chosen to adhere to a standard set of practices carried out to filter outdated, irrelevant, incomprehensible, unreadable, and irrelevant documents. For example, the term energy is quite common in other fields of scientific study and thus may be part of the heading, but the text may not be relevant to the research. The screening phases were sequential i.e., the papers satisfying the inclusion and exclusion criteria were considered during the second round where titles and abstracts were read, and no relevant papers were screened out.

To effectively execute and report this process, we used the elements of preferred reporting elements for systematic review and meta-analysis (PRISMA) methodology (see Fig. 1).

The search was restricted to the literature categories of conference and journal papers published between 2018 and 2022 to include the latest research trends and exclude outdated papers, with search terms appearing in the title or abstract. Moreover, the word “energy” is common in different domains such as molecular chemistry, thermodynamics, wireless communication, physics, astrophysics, and many other domains including learning and other sociological aspects, thus such field of study was excluded from search results. Some databases do not allow such filtering at the time of searching, in such cases further filtering is required manually. Such manual filtering was performed based on the above-defined criteria and methodology.

The execution of SQ on different databases yielded the following number of search results that were filtered as shown in Table 2:

Out of 956 search items for both search strings SQ1 and SQ2, 537 items were removed as they did not meet the required criteria of content type, such as old records, table of contents for a conference proceeding, welcome notes, etc. Moreover, a set of 226 items were removed as they were not found to be relevant based on a thorough reading of the title and abstract from the search result. The remaining 193 items were then sorted according to the title to search for duplicate results listed across different databases. A total of 37 duplicate results were found. A total of 156

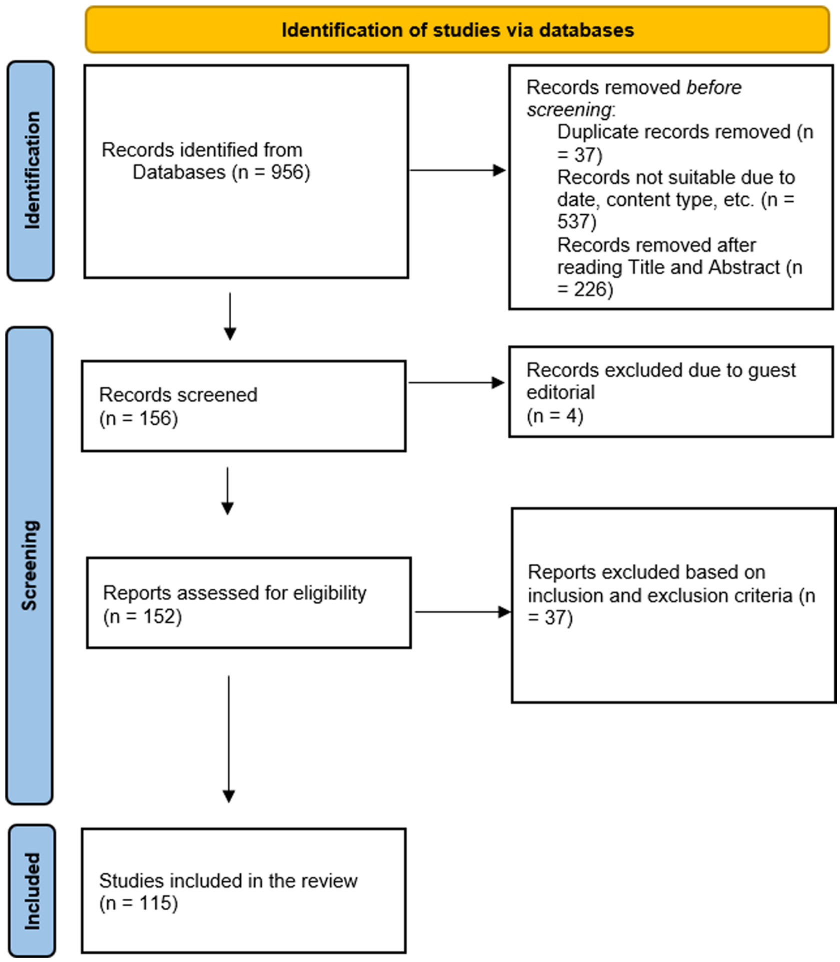


Fig. 1 Selection of literature using PRISMA methodology

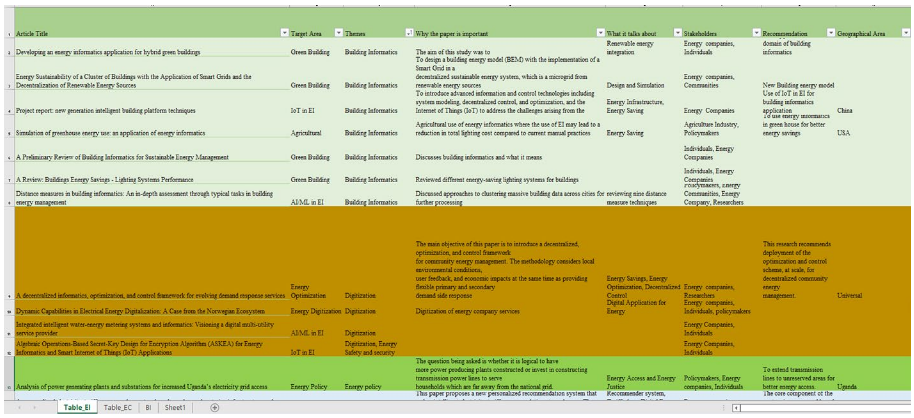
Table 2 Filtering of search result through the screening process

Databases	Total number of papers after search (SQ1 + SQ2)	Total number of papers after the first screening	Total number of papers after the second screening	Total number of papers after removing duplicates
ACM	(18 + 0) **18**	18	14	37
IEEE	(159 + 2) **161**	85	20	
Scopus (Elsevier)	(572 + 9) **581**	122	55	
Web of Science	(102 + 94) **196**	194	104	
Total	(851 + 105) **956**	419	193	156

unique results were found after this exercise. These results were then further analyzed based on full-text reading according to exclusion and inclusion criteria.

Data analysis and extraction

For the papers included in this study, full-text reading was performed to find answers to the research questions mentioned earlier.



	Article Title	Target Area	Themes	Why the paper is important	What it talks about	Stakeholders	Recommendation	Geographical Area
2	Developing an energy informatics application for hybrid green buildings	Green Building	Building Informatics	The aim of this study was to	Renewable energy integration	Energy companies, Individuals	domain of building informatics	
3	Energy Sustainability of a Cluster of Buildings with the Application of Smart Grids and the Decentralization of Renewable Energy Sources	Green Building	Building Informatics	To design a building energy model (BEM) with the implementation of a Smart Grid in a decentralized sustainable energy system, which is a microgrid from renewable energy sources	Design and Simulation	Energy companies, Communities	New Building energy model	
4	Project report: new generation intelligent building platform techniques	IoT in EI	Building Informatics	To introduce advanced information and control technologies including system modeling, decentralized control, and optimization, and the Internet of Things (IoT) to address the challenges arising from the	Energy Infrastructure, Energy Saving	Energy Companies	Use of IoT in EI for building informatics application	China
5	Simulation of greenhouse energy use: an application of energy informatics	Agricultural	Building Informatics	Agricultural use of energy informatics where the use of EI may lead to a reduction in total lighting cost compared to current manual practices	Energy Saving	Agriculture Industry, Policymakers	To use energy informatics in green house for better energy savings	USA
6	A Preliminary Review of Building Informatics for Sustainable Energy Management	Green Building	Building Informatics	Discusses building informatics and what it means		Individuals, Energy Companies		
7	A Review: Buildings Energy Savings - Lighting Systems Performance	Green Building	Building Informatics	Reviewed different energy-saving lighting systems for buildings		Individuals, Energy Companies		
8	Distance measures in building informatics: An in-depth assessment through typical tasks in building energy management	AI/ML in EI	Building Informatics	Discussed approaches to clustering massive building data across cities for further processing	reviewing nine distance measure techniques	Policymakers, Energy Communities, Energy Company, Researchers		
9	A decentralized informatics, optimization, and control framework for evolving demand response services	Energy Optimization	Digitization	The main objective of this paper is to introduce a decentralized, optimization, and control framework for community energy management. The methodology considers local environmental conditions, user feedback, and economic impacts at the same time as providing flexible primary and secondary demand side response	Energy Savings, Energy Optimization, Decentralized Control	Energy companies, Researchers	This research recommends deployment of the optimization and control scheme, at scale, for decentralized community energy management.	Universal
10	Dynamic Capabilities in Electrical Energy Digitalization: A Case from the Norwegian Ecosystem	Energy Digitization	Digitization	Digitization of energy company services	Digital Application for Energy	Energy companies, Individuals, policymakers		
11	Integrated intelligent water-energy metering systems and informatics: Visioning a digital multi-utility service provider	AI/ML in EI	Digitization			Energy Companies, Individuals		
12	Algebraic Operations-Based Secret-Key Design for Encryption Algorithm (ASKEA) for Energy Informatics and Smart Internet of Things (IoT) Applications	IoT in EI	Digitization, Energy Safety and security			Energy Companies, Individuals		
13	Analysis of power generating plants and substations for increased Uganda's electricity grid access	Energy Policy	Energy policy	The question being asked is whether it is logical to have more power producing plants constructed or invest in constructing transmission power lines to serve households which are far away from the national grid.	Energy Access and Energy Justice	Policymakers, Energy companies, Individuals	To extend transmission lines to unreserved areas for better energy access.	Uganda
				This paper proposes a new personalized recommendation system that	Recommender system,		The core component of the	

Table_EI Table_EC BI Sheet1

Fig. 2 Table showing the thematic classification for the SLR

Furthermore, a thematic classification of the reported paper was performed based on the guidelines that focused on the following aspects (a) identifying the target area of the literature found, (b) the theme it discusses, (c) why the literature is important, (d) what it talks about, (e) who are the stakeholders the literature is addressed to, (f) the recommendations made, and (g) the geographical area it focuses on. Microsoft Excel software was used to create two worksheets where each worksheet corresponded to the topic of EI and EC. In both the worksheet a table was created to note down the respective focus points of the paper based on above discussed thematic classification guidelines. The literature was then color coded to correspond to a theme as shown in Fig. 2. This process helped identify answers for the RQs as different themes could be identified based on the focus of the literature along with other factors such as identifying the stakeholders, their information needs, and future challenges. Each paper was classified into different themes and the target area that the research paper was advancing. For example, a paper discussing the use of the Internet of Things (IoT) in the domain of building informatics will be classified under the building informatics theme with a target area of IoT in EI (Zhao et al. 2018). Similarly, a paper describing the application of AI/ML in EI will be one target area, however, the domain of such application may vary between energy business (Krome and Sander 2018) or energy optimization (Akhtar et al. 2022) or energy forecasting (Williams and Short 2020), or energy management (Heghedus et al. 2019b). At times, the same article may have multiple themes because of the different domains the article may have influenced (Eissa and Awadalla 2019). This process is repeated for literature obtained after filtering search results using exclusion criteria for both SQ1 and SQ2, which also helps us answer RQ1 and RQ2. Moreover, as a result, we obtain common themes and target areas across both SQ1 and SQ2, which helps us answer RQ3 as shown in the Result section.

Results

This section answers the RQs in detail based on the SLR process described in the Methodology section. In addition, a word cloud, or tag cloud was generated from the list of keywords, as it has been found to be a very effective tool for text summarization or visualization method for text as well as to provide a visually appealing and intuitive overview

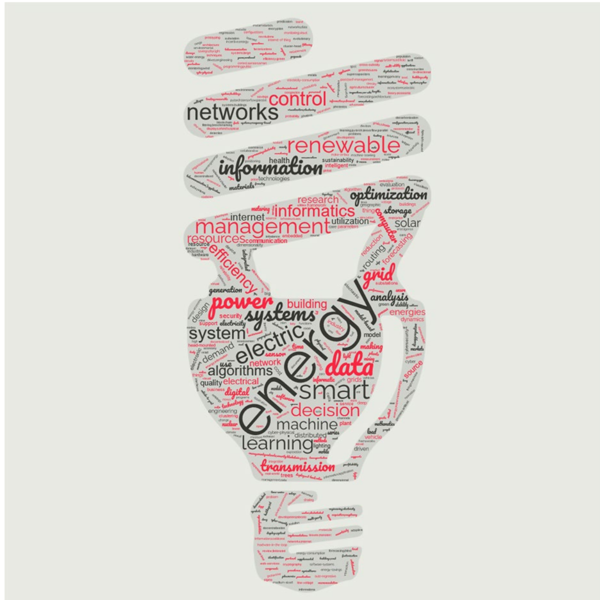


Fig. 3 Word cloud of keywords from the literature reviewed

of text by showing the word that occurs most commonly as most prominently (Heimerl et al. 2014). The word cloud generator took the list of all keywords from the selected article and generated a word cloud based on the frequency of words that were repeated most. The most repeated words are highlighted in terms of size, deeper color, and bolder text. This method helped in ascertaining whether the literature obtained is relevant or not, as it is a crude way of identifying the contours of potential themes and the general focus of the literature selected. This process can be considered an inexpensive filter to apply before more detailed analysis is carried out. It also familiarized us with upcoming themes expected to be obtained after the classification exercise. The word cloud obtained using the online tool is shown in Fig. 3, which outlines, based on the highlighted text, that the literature selected is relevant to the topic of research.

RQ1—what are the main themes explored in the domain of Energy Informatics?

The main themes explored in the domain of Energy Informatics based on thematic classifications are listed below in Table 3. Table 3 is arranged based on the frequency of themes identified in the article. In the EI domain, energy management is the most researched theme closely followed by energy technology, energy forecasting, and energy safety. Given below is the list of each theme, arranged in descending order of frequency, identified along with a detailed explanation of the theme and what these themes consist of and other relevant details about the literature concerning the theme and research focus of this literature. All these themes are discussed in detail in the following sub-sections. Figure 4 depicts the recent themes that expand from previously discovered themes that were identified based on the goals of the EI domain (Goebel et al. 2014). The new research themes are listed below the previously identified themes as they can be classified either under smart energy saving systems, as literature in energy management theme or energy technology theme, as well as energy forecasting theme, has energy saving as a primary goal. Similarly, literature in energy economics, energy safety, and security, and energy digitization has smart grids has a critical role in the study discussed in the paper.

Energy management

Energy Management is an umbrella theme in the domain of EI encompassing the energy supply side as well as consumption side aspects of energy distribution and consumption, where energy informatics can play a critical role in meeting the goals such as reducing energy cost, energy consumption, energy loss, and increasing profit (Watson et al. 2010). Literature classified under this theme discusses the application of EI to meet some of the above-defined goals. For example, in Mentler et al. (2018) application of usability principles in energy control systems used in day-to-day energy management activity, is discussed which is critical for the safe and efficient functioning of energy systems. A significant focus is given to the human-centered design process to obtain cohesiveness between EI software and the usability engineering process for usability, safety, and security. Another critical aspect of energy management is to maintain the balance of energy demand and energy supply. An excessive demand if not met successfully, could strain the energy distribution infrastructure, resulting in load-shedding. This makes it important that energy systems are equipped to meet the demand and respond to it. Demand Response (DR) is a keenly researched topic in EI. It requires the construction of such programs that could bring balance in demand and supply based on the analysis of data, extracted from energy infrastructure. Such systems also can be used by the consumer to shift load based on dynamic pricing and reduce energy bills (Sangeeth and Mathew 2018). Such products are now increasingly being considered by energy firms, especially software integrated with ML and analytics that can help managers model scenarios to achieve a reduction of uncertain actions such as an unexpected peak demand day (Hodges and Salam 2018). Additionally, newer development like automated transportation systems running on renewable energy and other IoT-enabled cyber-physical systems has increased the requirement for accurate modeling based on reasonably accurate data (Bordin et al. 2020). Researchers are also realizing that the integration of renewable energy sources such as consumer-owned solar panels or wind turbines causes an additional layer of challenge, then there is battery-based secondary storage, that at times is used to balance fluctuation in demand and supply as well as serve as a secondary source. As such sources do not produce energy at a constant rate, and non-uniform energy generation strains the energy distribution network which needs to meet energy demand in fluctuating supply. To solve this problem researchers are exploring different algorithms and approaches and setups that can make managing this task easy (Danner et al. 2022; Yuan et al. 2021; Ahammed et al. 2022; Alahmed and Tong 2022; Richter and Staudt 2019; Förderer et al. 2021; Switzer and Raghavan 2021).

Energy technology

EI is also aiding advancement on multiple technology fronts related to energy, especially driven by growth in the adoption of autonomous electric vehicles, opening possibilities in bi-directional energy trading. For example, EI tech makes it possible that rooftop solar panel-generated electricity sold to the grid can be bought back or reimbursed at

Table 3 Themes identified in the energy informatics arranged based on the frequency

Themes	Frequency	References
Energy Management	11	Mentler et al. (2018); Sangeeth Mathew (2018); Hodges and Salam (2018); Bordin et al. (2020); Danner et al. (2022); Yuan et al. (2021); Ahammed et al. (2022); Alahmed and Tong (2022); Richter and Staudt (2019); Förderer et al. (2021); Switzer and Raghavan (2021)
Energy Technology	10	Tang et al. (2021); Schumilin et al. (2018); Cao et al. (2022); Babak et al. (2021); Song et al. (2021); Cheng et al. (2022); Heghedus et al. (2018); Stamelos et al. (2018); Lazgheb et al. (2019); Meier and Dunn (2021)
Energy Forecasting	8	Oprea et al. (2018a); Hoog et al. (2021); Krome and Sander (2018); Heghedus et al. (2019a); Akhtar et al. (2022); Williams and Short (2020); Heghedus et al. (2019b); Halkos and Tsilika (2021)
Energy Safety and Security	8	Sultan and Hilton (2019); Wang et al. (2021); Eissa and Awadalla (2019); Llaria et al. (2021); Sedlmeir et al. (2021); Jahromi et al. (2021); Wu (2019); Bugaev et al. (2021)
Building Informatics	7	Lim et al. (2018); Kalmiş et al. (2019); Garlík (2022); Zhao et al. (2018); Watson et al. (2018); Al-Ghaili et al. (2020); Li et al. (2021)
Energy Digitization	5	Idries et al. (2022); Stewart et al. (2018); Al-Ghaili et al. (2021); Luna et al. (2019); Williams et al. (2020)
Energy Economics	5	Li et al. (2019); Grosse et al. (2019); Li et al. (2017; Wederhake et al. (2022); Kirpes and Becker (2018)
Household Energy Consumption	4	Kumar and Bhattacharjee (2018); Oprea et al. (2018b; Virtsionis Gkalinikis et al. (2022); Ai et al. (2019)
Energy Decisions	1	Kavuma et al. (2021)

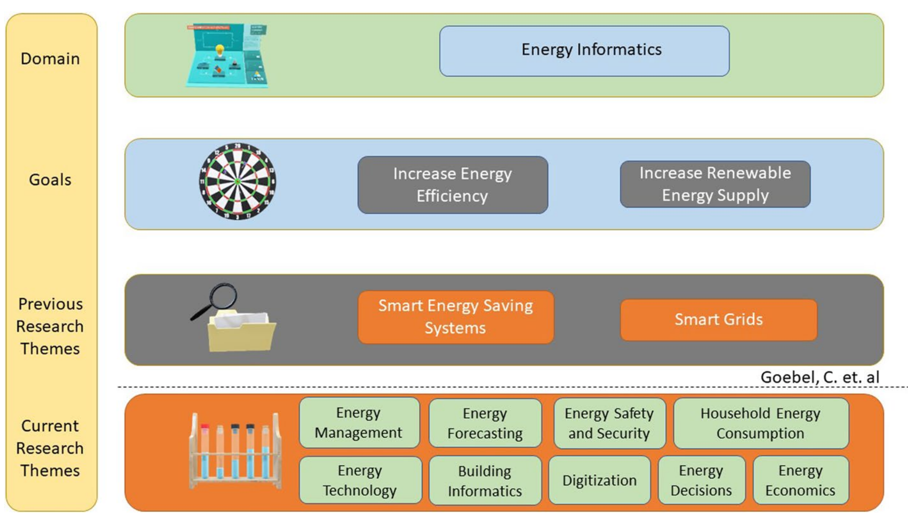


Fig. 4 Current themes identified in the domain of energy informatics expanded taking (Goebel et al. 2014) as a reference

EV charging stations (Tang et al. 2021). Another interest in this domain is in making a more accurate prediction of how far the vehicle will go on battery power (Cao et al. 2022). Another technological front that EI is aiding is in advancement related to grid management and balancing, especially with integrated renewable energy sources, which produce variable energy when measured continuously. Researchers are using tools such as machine learning, federated learning, etc. to better predict these fluctuations both on the generation side as well as the demand side. There is significant new technological research in the domain of demand response and to manage energy fluctuations (Schumilin et al. 2018; Babak et al. 2021; Song et al. 2021; Cheng et al. 2022; Heghedus et al. 2018). Some researchers have integrated IoT, or Raspberry Pi-based solutions or discussed new information ecosystems for better grid analytics (Stamelos et al. 2018; Lazgheb et al. 2019; Meier and Dunn 2021).

Energy forecasting

Energy forecasting is another theme that has received significant attention from researchers. Energy forecasting is particularly important for decision-makers at renewable energy generation and distribution companies to estimate the cost of balancing power (to meet additional demand) they would need to purchase from an external source. To this effect, researchers have compared many algorithms and methods to predict which algorithm would be better suited and what is the advantage of one over another (Oprea et al. 2018a; Heghedus et al. 2019a). Researchers have also advocated and demonstrated using seasonal conditions as a parameter in these calculations to achieve better accuracy (Hoog et al. 2021). Others have demonstrated how energy informatics can help in cheaper power purchase costs from the energy stock exchange (Krome and Sander 2018). In exhaustive research conducted at IIT Bombay, energy consumption data of the university was taken and analyzed for energy demand prediction. In the analysis, multiple machine learning algorithms were used on the dataset and their performance was analyzed (Akhtar et al. 2022). Similarly, other researchers have considered other scenarios like distributed energy generation sources to predict energy demand scenarios (Williams and Short 2020), use neural network methodology (Heghedus et al. 2019b), or use energy informatics data to represent different regions' energy consumption and renewable usage adoption pattern for visual understanding of the policymakers (Halkos and Tsilika 2021).

Energy safety and security

In geopolitics, energy is a strategic resource; thus, energy security is a critical aspect on which continued energy availability depends (Aronson and Stern 1984). In EI terms, energy safety and security occupy a different dimension which is different from physical safety and security as in the context of EI, it is virtual safety and security of energy data, energy systems, and private energy consumption information. Privacy, safety, and security issues become more prominent in settings where the energy community is sharing energy sources such as power generation or energy storage units, and intelligent buildings connected with smart grids (Wang et al. 2021; Llaria et al. 2021). Another aspect of energy safety is grid reliability, especially with decentralized renewable energy acting as a secondary source (Sultan and Hilton 2019). Decentralized renewable energy can result in fault current flow in different directions resulting in failure of protection logic and may result in energy outage which can be overcome by using EI to its full potential. For example, critical measurements such as transmission and sub-transmission level information along with accurate system-level demand data can help achieve unit protection and coordination of the demand and supply process (Eissa and Awadalla 2019). Blockchain as a technology is also aiding the safety and security aspects of energy informatics, such as trading green energy certificates (Sedlmeir et al. 2021). Similarly, Machine learning-based anomaly detection techniques may be used to detect cyber-attack on energy infrastructure (Jahromi et al. 2021). Dashboard-based applications as an information source for all cyber-physical energy systems or virtual applications used to model safety and security protocols on safety–critical energy generation units such as nuclear power plants are some examples of the safety-related applications of EI (Wu 2019; Bugaev et al. 2021).

Building informatics (BI)

Building Informatics is a major research theme in the domain of EI. BI involves collecting different types of data from multiple sources such as Heating, Ventilating, and Air-Conditioning (HVAC) systems, sensors, grids, and power storage for the purpose of analysis that helps in building energy management and decision-making (Lim et al. 2018). It may include information such as occupant data, smart home data, wind data, and seasonal parameters (Lim et al. 2018; Al-Ghaili et al. 2020). In this SLR there were around seven research items that were classified as having BI as their main theme, however, there are a few more articles that have more than one theme and BI is one of them.

In the area of BI, researchers have focused on many issues. For example, in one such research, software was developed that simulated the use of three different power sources such as central grid, personal solar power, and battery-based power storage as well as simulated dynamic energy pricing and other external factors for a small residential apartment to demonstrate how energy informatics can play a significant role in building energy management (Kalmiş et al. 2019). A further, more detailed, and technical discussion is carried out in another paper that discusses creating Building Energy Model (BEM) that has multiple energy components such as renewable and on-demand energy storage systems (Garlík 2022). Similarly, other researchers have focused on designing more decentralized control systems for buildings (Zhao et al. 2018), demonstrated the effective use of EI in saving energy consumption of a greenhouse (Watson et al. 2018), reviewed different energy-saving lighting systems for buildings, and discussed approaches to clustering massive building data across cities for further processing (Al-Ghaili et al. 2020).

Energy digitization

Energy digitization is an emerging field for IT companies providing digital solutions across the energy lifecycle, especially, digital consumer accusations (Idries et al. 2022). In many countries, such as Finland and Norway, changing energy service provider is seamless and generally a few clicks away. More countries are offering similar flexibility to their customers; thus, energy companies need to provide such applications from which customers can be acquired digitally (Idries et al. 2022). Similar scope exists in the digitalization of heated water supply to households or using encryption for the transmission of data in connected energy devices (Stewart et al. 2018; Luna et al. 2019). Digitalization of energy services also deals with providing energy safety using algorithmic management and control of energy demand and infrastructural response (Williams et al. 2020) and privacy related to energy data (Al-Ghaili et al. 2021).

Energy economics

Energy economics is another significant theme that has been driving research and investment in EI. In addition, the nature of the energy business is also changing, forcing energy companies to innovate new business models to maintain a steady revenue stream in a fluctuating energy market (Grosse et al. 2019). The energy economics theme spans both the demand and supply sides, and similarly, the application of EI spans both the demand and supply sides (Li et al. 2019, 2017). For example, in Li et al. (2019) a personalized tariff recommender is discussed that can be used to schedule more resource-intensive appliances when the energy tariff is low resulting in less consumption of expensive electricity power, a win–win for both the end consumer and energy-providing company. Another research on a similar line advocates the application of EI in making electricity by reducing energy consumption demand instead of buying expensive electricity at peak hours (Wederhake et al. 2022). On the other hand, on the supply side, energy players may offer new choices to users to form a community of renewable energy-generating and consuming households (Grosse et al. 2019). Another possibility is that different players such as individual aggregators, supplier coalitions, and macro-grid operators indulge in small-scale renewable energy trading using a novel approach (Li et al. 2017). With the advancement of Electric Vehicle (EV) technology as well as blockchain technology, the two can be fused together to allow sharing of peer-to-peer charging stations based on blockchain technology, helping to overcome the shortage of charging stations of the same vendor (Kirpes and Becker 2018).

Household energy consumption

Using EI for reducing household energy consumption has also received considerable focus from researchers, where the focus has been on tracking end-user consumption patterns and device usage records to predict demand timelines, based on which energy can be purchased for less energy cost (Kumar and Bhattacharjee 2018; Oprea et al. 2018b; Virtsionis Gkalinikis et al. 2022). Predicting household consumption largely depends upon Non-intrusive Load Monitoring (NILM) based devices that use predictive modeling, and device electric usage signature to predict which device is used when (Kumar and Bhattacharjee 2018; Virtsionis Gkalinikis et al. 2022). Researchers are exploring scenarios where an automated system will be able to schedule such appliances based on low power tariffs, saving electricity bills for both consumer and distribution companies (Oprea et al. 2018b). However, such monitoring raises privacy concerns, which can be addressed by new technological solutions such as blockchain (Wang et al. 2021; Ai et al. 2019).

Energy decisions

Energy informatics can also be used to quantitatively evaluate policy decisions in terms of policy objectives and policy output. For example, Uganda-based researchers analyzed data to realize that the government can do a better job if they invest in upgrading energy transmission infrastructure, for surplus power to reach the demand center (cities) instead of creating new expensive power plants (Kavuma et al. 2021).

RQ2—what are the main themes explored in the domain of Energy Citizenship?

Energy citizenship is a term that has many manifestations for its meaning. It encompasses the public's awareness about climate change and their responsibility towards it; equity, and justice when it comes to using renewable energy, considering the energy poor who may not be able to afford more costly renewable energy sources; and collective energy actions such as setting up a community-based renewable energy infrastructure or cooperatives (Devine-Wright 2012). Energy citizenship has psychological, legal, and economic aspects. The psychological aspects deal with citizens' attitudes toward energy transition. Legal aspects deal with laws allowing citizens to participate in the energy transition by generating and commercializing the energy generated. The economic aspect deals with the public's ability and right to participate in energy transition without making an economic contribution (Hamann et al. 2022). The main themes explored in the domain of Energy Citizenship based on thematic classifications are listed below in Table 4. Table 4 is arranged based on the frequency of themes identified in the article. It can be seen that in the EC domain, energy democracy is the most researched theme closely followed by energy behavior, energy literacy, energy policy, and energy business. Given below is the list of each theme, arranged in descending order of frequency, identified along with a detailed explanation of the theme and what these themes consist of and other relevant details about the literature concerning the theme and research focus. Figure 5 depicts the result of recent themes identified that are encapsulated under previously discovered perspectives. Figure 5 depicts the recent themes that expand from previously discovered perspectives that were identified in the EC domain (Hamann et al. 2022). The new research themes are listed below the previously identified perspectives as they can be classified either under legal perspective, as literature in energy democracy theme deals with the legal framework and political focus towards energy. Similarly, the literature on the energy behavior theme focuses on psychological aspects to bring in a measurable change in energy behavior discussed in the paper.

Energy democracy (empowerment, justice, and prosumerism)

Energy Democracy is the most significant theme discussed in the domain of Energy Citizenship. In one paper it has been described as "epitomizes hopes in the energy transformation, but remains under-defined, acting as a political buzzword rather than a real concept" (Szulecki 2018). Energy democracy is a socio-political movement that in practice focuses on increasing the role of individual prosumers, energy communities, and municipal bodies in certain functions of energy generation and consumption that was earlier carried out by energy companies (White 2019; Szulecki 2018). The focus in energy democracy is on the redistribution of energy processes such as production and consumption along with socio-political concepts of "empowerment, participation and some notion of fairness and legitimacy, as well as environmental sustainability" (Szulecki 2018). Another aspect is that the energy transition is driven by changes in technology which require wider participation of prosumers (installing solar panels on homes and buildings), which brings in a new economic and socio-political context that was earlier restricted to institutions, leading to the demand for the increased accountability and democratization of a sector that was previously not seen as requiring public

Table 4 Themes identified in the domain of energy citizenship

Themes	Frequency	References
Energy Democracy (Access, Equity, and Justice)	22	Zyl-Bulitta et al. (2019); Foulds et al. (2022); Anfinson (2022); Lennon et al. (2020); Wuebben et al. (2020); White (2019); Xexakis et al. (2022); Cantoni et al. (2018); Ryghaug et al. (2018); DellaValle and Czako (2022); Ringholm (2022); Santos et al. (2019); Cantoni (2022); Sanz-Hernández (2019); Allan et al. (2022); Boamah and Rothfuß (2020); Coy et al. (2021); Tsagkari (2022); Wahlund and Palm (2022); Bonnet et al. (2019); Veelen and Horst (2018); Lee (2019)
Energy Behavior	16	Button (2018); Lofhagen et al. (2018); Geerts et al. (2022); Szostek (2021); Llanos et al. (2019); Wees et al. (2022); Beauchampet and Walsh (2021); Contu et al. (2020); Phillips and Waitt (2018); Schall (2020); Mullally et al. (2018); Urquiza et al. (2018); Carvalho et al. (2022); Diego et al. (2018); Liu et al. (2020); Ambrose (2020)
Energy Literacy	8	Lizana et al. (2021); Yoho and Rittmann (2018); Ruiz-Mallén et al. (2022); Tryfonas et al. (2018); Harskamp et al. (2021); Mach (2019); Slaoui et al. (2017); Robina-Ramírez and Medina-Merodio (2019)
Energy Policy	6	Huh et al. (2019); Celata and Coletti (2019); Bezerr et al. (2021); Drożdż et al. (2022); Zuo et al. (2019); Moles-Grueso and Stojilovska (2021)
Energy Business	3	Hartmann et al. (2021); Simeoni et al. (2019); Toft and Rüdiger (2020)

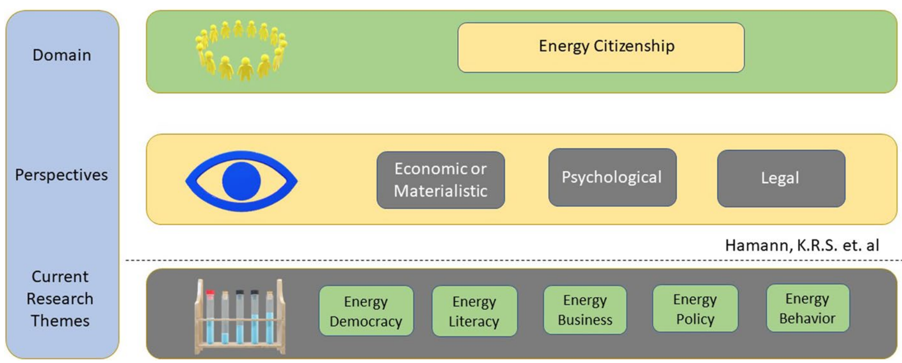


Fig. 5 Current themes identified in the domain of energy citizenship expanded taking (Hamann et al. 2022) as a reference

involvement. As energy transition affects society, energy democracy becomes important (Foulds et al. 2022; White 2019; Szulecki 2018).

Energy democracy as a concept exists because researchers understood that technology perceived as sustainable in one dimension may cause environmental or social problems in another. For example, establishing wind energy farms at sea has been resisted by marine ecologists. Similarly, direct participation or uniform representation does not necessarily result in social and environmental benefits, but researchers have found that the prosumer-based organization in comparison exhibits fewer negative effects on society mainly due to the design and planning involving greater consideration of the local contexts and needs of communities. Thus, prosumer-based energy cooperatives produce more positive local effects (Zyl-Bulitta et al. 2019). Researchers have evaluated different tools (Wuebben et al. 2020) and have used frameworks (Bonnet et al. 2019) to analyze different energy projects with a view of political ecology and environmental conflicts (Santos et al. 2019), some to understand the reason for failure or resistance from local communities (Cantoni et al. 2018; Cantoni 2022), and some for their success (Lee 2019), others have used data-driven platforms for stakeholder engagement (Xexakis et al. 2022). Researchers have also investigated authoritative regimes indulging in colonial energy conflict, leading to hostile citizens (Allan et al. 2022), and government schemes of distributing renewable energy units in remote locations, to realize that such initiatives may not be perceived just by the recipients (Boamah and Rothfuß 2020). Energy justice, a major aspect of energy democracy is linked with self-determination (Allan et al. 2022) and it must meet the needs and vision of the society (Boamah and Rothfuß 2020).

Researchers have compared the energy transition journey of communities in Europe with their counterparts in the US and have found that the European renewable energy transition does provide some empowerment to citizens (right to produce and sell energy) (Anfinson 2022), however, in criticism, it can be said that energy transition in Europe tries to place the ownership or burden of executing creation and operation of energy production infrastructure on European citizens (Anfinson 2022; White 2019). This, researchers warn, can result in fatigue, a false sense of positive action, dilution of citizenship, and result in citizens mediating in environmental politics (Anfinson 2022; Lennon et al. 2020). Researchers have argued that this individualization of energy citizen who is also a consumer does not consider social complexities such as energy poor (Lennon et al. 2020; DellaValle and Czako 2022) and energy transition should not be viewed as a mere substitution of one fuel for another as it presents challenges and opportunities to rethink how our society and politics around energy is executed (White 2019).

When discussing energy citizenship, it has been argued that materialistic possession of objects (rooftop solar panels, electric heaters, smart meters, electric vehicles, etc.) allows prosumers to interact with new objects and technology which facilitates their participation and may act as the initiation of energy citizenship or energy democracy (Veelen and Horst 2018), yet technology on its own, does not create energy citizenship. Energy democracy is nourished by the interaction and participation of citizens in a social context which may be facilitated by technology (Ryghaug et al. 2018). Therefore, participation research has gained significance in energy citizenship research. There are different levels of engagement and individual preferences of participants, yet they need to function within socially acceptable norms (Ringholm 2022). In energy democracy, the participation of citizens is considered a key requirement. The participation of citizens may manifest in conflicts that will need to be addressed. These conflicts may manifest in the form of access, where certain people based on their economic might may be allowed to participate and others may be excluded, which would be a case of energy injustice (Veelen and Horst 2018). Attention has also been given by researchers to the cause of the energy poor (people who do not have an economic or geographic or social means to participate in transition) and how policymakers and energy projects define their role, including gender-based fare distribution (Tsagkari 2022). Researchers have found that some projects and policies do create conditions that help empower mechanisms to start converting passive consumers into energy citizens (DellaValle and Czako 2022; Coy et al. 2021; Lee 2019). A study of media coverage in Spain showed media too has advocated energy justice and collective empowerment as tools to achieve energy citizenship (Sanz-Hernández 2019) and a comprehensive review of the literature point to three major pillars of energy democracy: Empowerment, Justice, and Prosumerism (Wahlund and Palm 2022).

Energy behavior

Influencing people's attitudes and behavior towards using Energy is considered a significant research area to influence reduced energy consumption, a value expected of an ideal energy citizen in the political context. With policymakers, adopting nudging as a tool to steer and manipulate the public in meeting a policy objective, it has been viewed negatively as it does not empower nor allow the public to engage in the rights and responsibilities of a democracy (Button 2018). However, environmental, and economic aspects are the most significant drivers of environmental citizenship in comparison to social motivation (Lofhagen et al. 2018). Individual or household energy consumption behavior is seen by some policy maker as a very significant strategy to address environmental issues, while others warn that the right approach is collective behavior and not individual (Geerts et al. 2022) even though individual personality traits have a significant impact on energy citizenship behaviors (Szostek 2021).

Other factors that have a positive impact on energy transition behavior are rewards and the acquisition of new knowledge that can be applied in real life and adopting a new sustainable habit that can be practiced (Llanos et al. 2019; Wees et al. 2022). For example, rewarding users for their recycling activity has encouraged recycling (Diego et al. 2018). Similarly, wind farms have raised consumer intrigue and have given rise to 'green tourists' who visit such places with the intent to engage in wind farm activities and experience environmental citizenship (Liu et al. 2020). Another aspect that has come to the surface is that energy generation which earlier used to be a major employer and needed people to participate actively (like mining coal by hand) has now drifted away from public conversation and everyday life and appears only at times of controversy. Thus, activities like 'Walking with energy' where people visit local energy production units to understand and see how energy is generated, have benefited citizens by inducing healthy curiosity and imparting basic knowledge. Activities, which offer opportunities for social learning, are carried out in an area embedded with the community and society and engage body and mind have been found to be most effective in bringing in lasting changes in attitudes and behavior (Phillips and Waitt 2018; Ambrose 2020).

Researchers have also identified that policymakers perceive citizens as central actors in the transition story who must be meaningfully engaged to achieve transition goals and thus it is important to remove barriers that are mostly (a) economical, and (b) practical hassles (lack of knowledge, resource, etc.) associated with transitioning (Beauchampet and Walsh 2021). Other research has been carried out on how people perceive different energy sources, their attitudes toward them, and how people's personal lifestyle influences their views (Contu et al. 2020).

Researchers have investigated the demographic of the people who are investing in the renewable energy business in Germany and have found them to be mostly male with a higher income, and higher education, who live in a more rural area compared with the overall population, exhibit strong pro-environmental beliefs and behaviors, and positive attitude for active citizenship. They also suggested that such individuals also look for a form of non-financial or "psychic return" from the investment, as it seems to be an important factor for investment (Schall 2020).

It has been found that the problem of sustainable energy and the challenge of transitioning to a low-carbon, climate-resilient, environmentally sustainable energy solution requires that (a) the energy system change from being exclusively Government and utility led, to one where citizens and communities will increasingly be participants in renewable energy generation, distribution, and energy efficiency, (b) individualized citizen-consumer framing of energy citizenship to change to collective action rooted in the community, and (c) the need to develop mechanisms and instruments to make (a) and (b) possible (Mullally et al. 2018). It is required that the policymakers, energy companies, and energy consumers have a shared vision of desired energy future, to govern the energy transition by way of managing the expectations of the actors and systems involved in it. Participatory approaches have been found to promote the co-construction of a shared energy future, that is able to resonate with consumers and provide a common reference to the actors participating in its creation. Participatory approaches can also make transitions more democratic by subjecting them to a broader influence and control from the citizen. Thus, policymakers would require that they produce such energy systems which are plural and dynamic in nature and is responsive and accountable to the public (Urquiza et al. 2018; Carvalho et al. 2022).

Energy literacy

Energy Literacy is a method to impart values of Energy Citizenship primarily to school students and university-level students. Researchers have employed a novel method to support environmental knowledge, to empower students to adopt sustainable practices (Yoho and Rittmann 2018; Harskamp et al. 2021). Schools are considered a quite powerful and effective tool to encourage and engage communities in sustainable practices (Lizana et al. 2021). Thus, many researchers have evaluated school textbooks or educational practices to determine how well environmental topics have been covered and have advocated the need to modify the curriculum to address the skill gap (Tryfonas et al. 2018; Mach 2019; Slaoui et al. 2017; Robina-Ramírez and Medina-Merodio 2019). Researchers have also used activity-based methods, such as community-based initiatives to have a more transformative learning experience resulting in better reflection capabilities and critical awareness in students (Ruiz-Mallén et al. 2022).

Energy policy

Energy policy has been identified as a major theme that influences Energy Citizenship. Many governments have designed policies to promote transitioning to renewable energy sources (Huh et al. 2019). The effect of the policy on energy transition is long-term but gradual, and successful implementation requires that the energy consumer must feel that their needs are being addressed while they transition to new energy technology and energy business should have a more predictable policy outlook (Celata and Coletti 2019; Bezerr et al. 2021). Researchers have analyzed different countries based on three parameters: (1) energy systems, (2) energy citizenship, and (3) digital technology and have found that countries that rank more on these parameters have been better placed in transition pathways (Huh et al. 2019). Researchers have also studied the policies of government and institutions to analyze how well they are helping achieve stated objectives and have mostly found them lacking in many aspects such as socioeconomic considerations of energy consumers when designing energy policy. However, if any intervention has economic benefits and is technically advanced (solves some problems for the end-user), its adaptability increases (Drożdż et al. 2022; Moles-Grueso and Stojilovska 2021). One research analyzed the effectiveness of the policy of giving subsidies for electric vehicle technology (Zuo et al. 2019).

Energy business

Energy business as a theme has been rarely discussed when discussing energy citizenship. Energy companies are not viewed or perceived to have any business interest in promoting renewable energy sources, however, researchers have identified that it is not always true (Hartmann et al. 2021). Some traditional energy companies are heavily invested in the renewable energy sector due to rapid growth in the market as well as the expertise of running an energy company surely, helps in managing the new business as well (Hartmann et al. 2021). Also, researchers found regulatory pressure and societal pressure tend to make energy businesses invest in renewable energy, in the absence of which organizations may employ greenwashing (a term used to describe the fraudulent practice of not adhering to true green practices yet making the claim) (Hartmann et al. 2021; Toft and Rüdiger 2020). Researchers have also demonstrated that industrial units can also contribute to energy saving by modifying their processes and adopting sustainable practices, which can in turn help generate revenue. For example, excess heat from the industrial unit can be used for district heating if stakeholders' needs are addressed (Simeoni et al. 2019).

RQ3—how do energy informatics and energy citizenship interconnect?

EI aids energy citizenship. Energy informatics has the potential to make energy transitioning a citizen-centered as well as a citizen-driven initiative. EI makes it possible to visualize energy that is seemingly invisible and helps in increasing awareness and promotes environmental actions as it allows diverse modes of participation and engagement with objects of transition (Ryghaug et al. 2018). EI also allows a high volume of data gathering about technical and social aspects of energy transition and acts as a link between energy communities and energy technologies (Wuebben et al. 2020). For example, smart meters allow people to get more aware of their energy consumption patterns and can allow them to know dynamic energy pricing, which can help change consumption patterns, such as avoiding running resource-intensive appliances during non-peak hours, to save on higher electricity tariffs, or when retail electricity prices are low (Bourgeois et al. 2014). Additionally, policymakers and energy companies employ EI for decision-making, policy creation, and regulatory decisions (Santos et al. 2019).

Energy transition in practice will require a fundamentally different form of "thinking, actions, systems, and structures" (Coy et al. 2021), and EI allows policymakers and other stakeholders to understand different aspects of energy projects through data (Xexakis et al. 2022). For example, energy businesses using EI can use historical demand data to schedule energy purchases at low tariffs (Bourgeois et al. 2014).

The decentralization of energy production would require wider adoption of new energy generation practices, integration of microgrids to integrate small clusters of renewable energy production sites, managing local energy storage infrastructure, use of smart devices, and employment automation, and all these processes critically rely on EI. Energy citizenship requires participants to have energy literacy, access to energy technology, and knowledge about energy technology and regularly monitor their energy behavior and all these activities need EI to effectively capture data and broadcast knowledge (Wahlund and Palm 2022).

EI helps establish transparency through the exchange and processing of data and sharing Information between policymakers, energy businesses, and energy citizens as shown in Fig. 6, which helps in establishing trust between stakeholders and promotes meaningful interactions (Simeoni et al. 2019). It helps remove barriers to participation, such as access to energy, energy literacy, and knowledge of energy policy (Beauchampet and Walsh 2021). EI also significantly impacts energy transition behavior as it facilitates the acquisition of new knowledge that can be applied to practice a new energy habit that over time turns into energy behavior (Llanos et al. 2019; Wees et al. 2022; Diego et al. 2018). Moreover, EI also has the potential to aid in improving energy literacy by making sure information related to energy technology and tools is understandable by the end users, who would then consume this information to supplement their learning as well as the perspective of what it means to be an energy citizen (Yoho and Rittmann 2018; Harskamp et al. 2021). It is critical to note that the focus of energy literacy literature has mostly been on energy companies and less on communal aspects of energy generation and consumption.

This paper has identified *nine prominent research themes in the domain of EI* and *five prominent research themes in the EC domain* that have expanded the previously suggested research themes and perspectives. These themes are expanding continuously as more applications and methods are turning successful in achieving goals like reducing energy consumption, energy cost, and energy loss through the application of energy informatics-based tools and technologies.

Energy informatics plays a critical role in realizing the concepts of energy citizenship by associating meaning and values to energy data. However, energy informatics needs to broaden its perspective from considering individual consumers and behavior to more community-driven perspectives and socially acceptable viewpoints. The energy transition is going to shift the socio-political interaction with energy as more communities adopt and build on sustainable practices. Given below in Table 5 are the different energy information themes which are relevant for different stakeholders as they interact in the energy ecosystem.

Discussion

In this review of EI from the perspective of energy citizenship, we find that even though the energy sector has moved away from the traditional way of central energy production and distribution into a distributed energy generation method involving clusters of microgrids, it has not moved away from the traditional view of individualization of energy consumption, which individualizes the problem of reducing energy consumption i.e., places the burden on consumers to participate in energy transition and absolves government and politicians from the failure of energy transition projects (Lennon et al. 2020). Energy citizenship needs energy projects to pay importance to data that capture parameters of energy citizenship, empowerment, equity, and justice from a socially

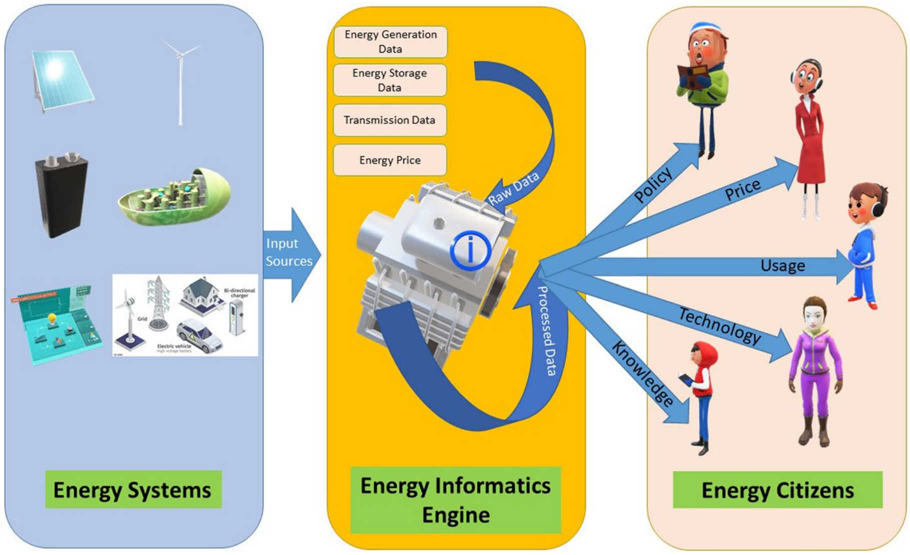


Fig. 6 Energy Informatics makes energy systems understandable to energy citizens

acceptable community perspective (Xexakis et al. 2022). In energy citizenship, finding what constitutes meaningful engagement and how engagement activities must be viewed from the perspective of collective behavior change and not as a passive market consumer is important (Foulds et al. 2022). Energy informatics along with energy technology creates new experiences, social learning, and interactions among the stakeholders and can employ tools such as co-design or citizen science-based approaches to enhance the collective understanding of energy transition goals, objectives, actions, and collective responsibility of participants as well as policymakers and energy businesses while implementing the project (Foulds et al. 2022; Wuebben et al. 2020; Xexakis et al. 2022; Koning et al. 2020).

Based on analysis of the state of the art during this SLR, it has been identified that energy informatics research has diversified into many sub-topics such as energy management, energy business, energy forecasting, etc. Similarly, energy citizenship has evolved as concepts of energy justice, energy poverty, and energy literacy are broadening the scope of the energy citizenship domain. Moreover, energy citizenship gets influenced by energy informatics as energy informatics can help in translating technical data into more understandable and usable knowledge for the general public.

In a nutshell, we discovered that energy informatics has been more focused on the individual as an energy citizen, for example, existing energy information research focuses on extracting and presenting information that can be used by one individual to take energy decisions, like, installing solar panel (generally taken by someone in a household (mostly male, earning member, technically aware, feudalistic setup, or a person of power in residential units) (Tsagkari 2022), or changing their schedule according to energy demand (Bourgeois et al. 2014). The information presented like potential energy saving or lesser energy cost is designed for one household where many individuals may live but yet is considered as one single entity. Additionally, energy citizenship has been criticized for putting the burden of transition on an individual who has to adopt

Table 5 EI and EC themes relevant for stakeholders as they interact

EI & EC themes relevant to the stakeholders as they interact	Individual	Energy Community	Energy Company	Policymakers	Researchers
Individual	**Energy Behavior** Individual energy behavior could be adopted by other individuals through interaction and communication related to energy (Szostek 2021; Liu et al. 2020)	**Energy Policy** Individuals have information needs with the energy community which relates to the existing energy policy in the community, the process of joining the community, and their rights and responsibilities as members (Hamann et al. 2022; Goebel et al. 2014)	**Energy Economics** Individuals are dependent on energy company to get access to their consumption data, energy load and energy bills. Such information help individuals to understand their energy consumption (Grosse et al. 2019; Li et al. 2017; Wederhake et al. 2022)	**Energy Literacy** Individuals may gain new knowledge through interaction with policymakers and during policy debates at the time of policy making (Harskamp et al. 2021)	**Energy Behavior** Individual energy behavior could be influenced by new energy research. For example, adoption of EV or through incentives (Szostek 2021; Diego et al. 2018)
	Energy Literacy Individual-level interaction related to energy has been found to be an effective method for increasing energy literacy (Yoho and Rittmann 2018)	**Energy Democracy** Individuals taking part in the energy community further energy democracy by adding newer voices in the management of the energy community (Devine-Wright 2012; Goebel et al. 2014)	**Energy Business** In case of individuals selling their electricity to the grid, or in case of billing based on dynamic energy pricing, real time energy pricing and energy generation data becomes significant energy information (Grosse et al. 2019)	**Energy Policy** Individuals also learn about energy policy through policymakers when they discuss and communicate a policy in the media (Celata and Coletti 2019)	**Energy Literacy** Individuals can gain new knowledge by interacting with researchers as well as by taking part in energy research-related activities like the co-design of CLIs (Ruiz-Mallén et al. 2022; Peña and Jensen 2023)

Table 5 (continued)

EI & EC themes relevant to the stakeholders as they interact	Individual	Energy Community	Energy Company	Policymakers	Researchers
	Energy Policy Individuals also learn about policy changes through word of mouth when interacting about energy. Thus, energy policy should be easy to communicate (Celata and Coletti 2019)	**Energy Economics** Individuals involved in energy communities also generally have an economic stake in producing and selling green energy (Grosse et al. 2019)	**Energy Technology** Energy companies employ technology such as energy meters, EV charging units, etc. which may be unfamiliar to the user. In such cases, training, as well as manuals, may be required (Tang et al. 2021; Schumilin et al. 2018; Babak et al. 2021)	**Energy Democracy** Individuals may gain access to the policymaking process and may contribute their opinion, strengthening energy democracy (Foulds et al. 2022; Wuebben et al. 2020)	**Energy Policy** Individuals can gain a greater understanding of energy policy and its impact by getting familiar with energy policy research and its impact (Bezerr et al. 2021)
	Energy Democracy The energy democracy concept is strengthened by citizens exchanging energy information (Devine-Wright 2012) **Energy Technology** New energy technology gets publicity and recommendation from early adopters which increase trustworthiness in new energy technology (Tang et al. 2021)	**Energy Technology** For Individuals, joining an energy community may involve adopting newer energy technology, which could involve some amount of training and support that the energy community should be able to provide (Tang et al. 2021; Cao et al. 2022)	**Energy Safety and Security** Individuals also need the information to use electricity safely. Additionally, energy companies must build trust in individuals through their processes regarding their energy data and privacy (Aronson and Stern 1984; Wang et al. 2021; Llaria et al. 2021)		**Energy Democracy** Individuals by interacting with researchers can provide their viewpoints which add new perspectives for researchers to consider aiding energy democracy

Table 5 (continued)

EI & EC themes relevant to the stakeholders as they interact	Individual	Energy Community	Energy Company	Policymakers	Researchers
Energy Community	**Energy Management** Energy communities need individual energy generation data of their members to better manage their energy community (Sangeeth and S. and K Mathew, S., 2018; Hodges and Salam 2018; Bordin et al. 2020)	**Energy Policy** Energy communities can communicate with each other over energy policy and can form a consortium to collectively lobby for changes in energy policy (Huh et al. 2019)	**Energy Economics** Energy communities supply energy generated by them to energy companies that transmit energy through the electric grid and have an interest in energy pricing and energy demand data. Energy sold at a higher profit during peak demand time must be shared with energy communities (Li et al. 2017; Wederhake et al. 2022)	**Energy Democracy** Energy communities have the most critical role in realizing energy democracy and bringing it to life. Energy communities, thus need a clearer understanding of policy framework and policy objectives from policymakers (Wuebben et al. 2020; Santos et al. 2019)	**Energy Literacy** Energy Communities may work closely with energy researchers, or consume published energy research, which enhances energy literacy in communities (Mach 2019)
	Energy Digitization Energy communities are increasingly using digital tools and software to access the energy consumption and generation data of individual members (Idries et al. 2022)	**Energy Democracy** Energy communities may have events where multiple energy community perspectives as well as best practices can be shared, which strengthens energy democracy (Wuebben et al. 2020; Xexakis et al. 2022; Santos et al. 2019)	**Energy Decisions** Energy communities at times depend on energy companies to make energy decisions. For example, data provided by energy companies can help the energy community to plan how they should utilize their resources. For example, if more solar panels are needed (Kavuma et al. 2021)	**Energy Business** Energy communities are greatly impacted by energy policy changes and it can impact their energy business (Li et al. 2019, 2017)	**Energy Policy** Energy communities gain a greater understanding of energy policy and its impact by getting familiar with energy policy research and its impact (Huh et al. 2019; Bezerr et al. 2021)

Table 5 (continued)

EI & EC themes relevant to the stakeholders as they interact	Individual	Energy Community	Energy Company	Policymakers	Researchers
	Household Energy Consumption Energy communities need individual household energy consumption data of their members to predict energy demand and energy supply (Kumar and Bhattacharjee 2018; Oprea et al. 2018b; Virtsionis Gkalinikis et al. 2022)		**Energy Technology** Energy communities may need to adopt new technology, which may not be familiar to the community. In such a case some amount of training and support could be provided by energy companies (Stamelos et al. 2018; Meier and Dunn 2021)	**Energy Safety and Security** Energy communities also depend on policymakers for designing a policy that safeguards the interest of energy communities and provides energy security (Aronson and Stern 1984; Wang et al. 2021; Llaria et al. 2021) **Energy Economics** Energy communities are greatly impacted by energy policy changes and it can impact their energy cost as well as energy generation	**Energy Technology** Energy Communities can learn about new energy technology and its effectiveness by interacting with energy researchers (Schumilin et al. 2018; Babak et al. 2021)
Energy Company	**Energy Digitalization** Individuals are increasingly using digital tools and software to access energy consumption and generation data of individuals. This may require individuals to agree to share their personal data like energy consumption with energy companies (Idries et al. 2022)	**Energy Digitization** Energy communities can also employ digital tools to access the energy consumption and generation data of the community as a whole (Idries et al. 2022; Stewart et al. 2018)	**Energy Policy** Energy companies may communicate with each other over energy policy and can form a consortium to collectively lobby for changes in energy policy (Drożdż et al. 2022)	**Energy Policy** Energy companies are regulated by policymakers through energy policy, which means energy companies should have a clear understanding of energy policy and their responsibilities (Zuo et al. 2019)	**Energy Behavior** Energy companies can make use of energy behavioral research to design products that may lead to more energy saving (Llanos et al. 2019; Wees et al. 2022)

Table 5 (continued)

EI & EC themes relevant to the stakeholders as they interact	Individual	Energy Community	Energy Company	Policymakers	Researchers
	Energy Forecasting Energy companies need to predict energy demand, at different times of the day which allows them to pre-purchase energy from energy exchange. This requires individuals to share their electricity consumption patterns (Oprea et al. 2018a; Heghedus et al. 2019a)	**Building Informatics** Energy companies also additionally need energy consumption data from buildings, such as HVAC systems which consume significant energy (Lim et al. 2018)	**Energy Business** Energy companies may also come together to form energy consortium which allows them to pool their resources together for greater business growth and market (Li et al. 2019, 2017) **Energy Economics** Energy companies may decide together certain fees such as fixed charges in order to maintain market stability **Energy Decisions** Energy companies may take energy decisions such as more investment in infrastructure based on energy-related data such as energy demand and supply (Kavuma et al. 2021)	**Energy Business** Energy companies are greatly impacted by energy policy changes and it can impact their energy business. Thus, energy companies work closely with policymakers and need a predictable policy framework for further investment (Li et al. 2017; Wederhake et al. 2022) **Energy Decisions** Energy companies may take energy decisions based on policy changes by policymakers. For example, tax on coal may be more than tax on gasoline **Energy Safety and Security** Energy companies also depend on policymakers for energy safety which includes the security of energy sources, especially in a global energy economy. For example, a war between countries could stress energy sources (Sultan and Hilton 2019; Eissa and Awadalla 2019)	**Energy Policy** Energy companies may learn about the shortcomings or effectiveness of energy policy through research carried out by researchers (Drożdż et al. 2022; Zuo et al. 2019) **Energy Technology** Energy companies have a stake in the research and development of energy technology that can be commercialized by energy companies (Tang et al. 2021; Babak et al. 2021)

Table 5 (continued)

EI & EC themes relevant to the stakeholders as they interact	Individual	Energy Community	Energy Company	Policymakers	Researchers
Policymakers	**Energy Behavior** Policymakers can gain insight into individuals' energy behavior when they interact with energy. This allows them to create policy considering how individual energy practices may impact the implementation of energy policy (Button 2018; Geerts et al. 2022)	**Energy Democracy** Energy community interaction with policymakers can allow policymakers to get a collective view of energy transitioning at the community level. This could help policymakers design policies that can then improve energy justice and energy democracy (Wuebben et al. 2020; Santos et al. 2019; Bonnet et al. 2019)	**Energy Business** Policymakers mandate energy companies through energy regulators to disclose their energy generation, transmission, and distribution data as well as energy loss data. The consolidated input from energy companies allows policymakers to have a bird's eye view of the energy sector (Li et al. 2017)	**Energy Business** Policymakers interact among themselves to identify shortcomings in energy business policies as well as to have uniformity in energy business policy across different regions (Kirpes and Becker 2018)	**Energy Literacy** Policymakers gain more energy literacy by interacting with energy researchers as they may educate policymakers with new research outcomes (Slaoui et al. 2017)
	Household Energy Consumption Policymakers need to understand individual household consumption patterns which may influence energy tariff policy, such as dynamic energy pricing (Kumar and Bhattacharjee 2018; Oprea et al. 2018b; Virtsionis Gkalinikis et al. 2022)	**Energy Business** Policymakers also gain an understanding of how energy business is impacting energy communities, both in terms of growing their business as well as size (Grosse et al. 2019; Wederhake et al. 2022)	**Energy Economics** Policymakers also have access to energy companies' financial health and may use the information to modify their energy-related tax to achieve policy objectives (Li et al. 2017; Wederhake et al. 2022)	**Energy Policy** Policymakers interact among themselves to discuss energy policy outcomes as well as future energy policy directions (Celata and Coletti 2019; Moles-Grueso and Stojilovska 2021)	**Energy Policy** Policymakers gain a better understanding of policy outcomes when energy researchers evaluate energy policy objectively and based on data. Thus, energy researchers can influence policymakers by focusing on certain aspects of policy that may not be meeting policy objectives (Zuo et al. 2019)

Table 5 (continued)

EI & EC themes relevant to the stakeholders as they interact	Individual	Energy Community	Energy Company	Policymakers	Researchers
	Energy Democracy Individuals' interaction with policymakers can allow policymakers to get a first-person account of energy issues and problems people face related to energy. This could help policymakers design policies that can then improve energy justice and energy democracy (Foulds et al. 2022; Allan et al. 2022)	**Energy Economics** Policymakers also gain an understanding of how energy economics is impacting energy communities, both in terms of profit margin and operating costs (Grosse et al. 2019)	**Energy Safety and Security** Energy safety and security is a major aspect of delivering energy to the masses, and energy companies must ensure that energy is delivered in a safe and secure manner policymakers may create policies that mandate the same, including compensation in case of accidents (Aronson and Stern 1984; Wu 2019; Bugaev et al. 2021)	**Energy Democracy** Policymakers when interacting with each other may focus on creating energy policy that may enhance energy democracy. As well as learn best practices to aid energy democracy (Lennon et al. 2020; Allan et al. 2022; Boamah and Rothfuß 2020)	**Energy Democracy** Energy researchers can draw the attention of policymakers toward energy inequality, energy access problems, and energy justice, helping energy democracy to grow stronger (Lennon et al. 2020; DellaValle and Czako 2022)
Researchers	**Energy Behavior** Energy researchers have been studying individual energy behavior by engaging with individuals and have come up with novel ways to influence them (Szostek 2021; Liu et al. 2020)	**Energy Behavior** Energy researchers have closely studied energy communities to see how energy communities influence energy behavior at a communal level (Liu et al. 2020)	**Energy Technology** Energy researchers may collaborate with energy companies to develop new energy technologies as well as to evaluate new energy technologies (Stamelos et al. 2018; Lazgheb et al. 2019; Meier and Dunn 2021)	**Energy Policy** Energy researchers may interact with policymakers to understand energy policy as well as policy objectives. Energy researchers also interact with policymakers to identify current policy focus as well as future policy contours (Wuebben et al. 2020; Bezerr et al. 2021; Drożdż et al. 2022)	**All themes** When energy researchers interact with each other all the themes of EI and EC are relevant for energy researchers, as different researchers focus on different issues. Moreover, energy researchers when interacting, may come up with new research ideas that can span multiple themes
	Energy Policy Energy researchers can gain knowledge about policy implications by interacting with individuals and collecting data for policy analysis (Drożdż et al. 2022)	**Energy Literacy** Energy researchers may involve the community to understand energy literacy among community members (Yoho and Rittmann 2018; Ruiz-Mallén et al. 2022)	**Energy Literacy** Energy researchers may collaborate with energy companies to understand how energy companies aid energy literacy (Ruiz-Mallén et al. 2022; Mach 2019)	**Energy Democracy** Energy researchers may need inputs from policymakers to evaluate energy policy on the basis of energy democracy concepts such as energy access, energy justice, and energy poverty (Coy et al. 2021; Wahlund and Palm 2022; Lee 2019)	

Table 5 (continued)

EI & EC themes relevant to the stakeholders as they interact	Individual	Energy Community	Energy Company	Policymakers	Researchers
	Energy Technology Energy researchers can study how individuals interact with new energy technology, which can help understand the impact of energy technology on society (Tang et al. 2021)	**Energy Policy** Energy researchers can gain knowledge about policy implications by interacting with communities and collecting data for policy analysis and its impact on energy communities (Celata and Coletti 2019; Bezerr et al. 2021) **Energy Democracy** Energy researchers study energy communities to understand how energy democracy manifests at a community level (Cantoni et al. 2018; Santos et al. 2019; Cantoni 2022)	**Energy Policy** Energy companies are major stakeholders in implementing energy policies and thus energy researchers need to involve in energy policy research (Celata and Coletti 2019; Bezerr et al. 2021) **Energy Democracy** Energy researchers may look into energy companies, in order to determine if energy companies are aiding energy democracy or hindering it due to economic considerations (Anfinson 2022; Lennon et al. 2020; DellaValle and Czako 2022)		

sustainable energy technology to 'qualify' as a modern ideal energy citizen. This paper argues that this outlook should change towards more communal aspects. We identified that the following open research questions exist, that need to be addressed for the wider transition towards renewable energy, where communities drive energy transition, feeling empowered and driven by the common greater good and individual benefit.

Open RQ-1: how do energy information needs differ in an energy community from an energy prosumer's perspective?

The energy transition is perceived differently as one moves forward on the transition pathway. Researchers have identified a nine-step process of transition where information needs differ (Koning et al. 2020). However, such research is generally focused on collecting information from one individual or a representative of one household. Additionally, in the EI research, data collected and processed are predominantly from the stakeholder's perspective of a policy maker, energy business, energy distribution companies, stand-alone households, or residential buildings. In energy transition projects involving communities, energy citizenship researchers have focused on increasing participation and inducing affirmative behavior, thus projecting energy transition as a moral obligation of an ideal citizen. Alternatively, for a more comprehensive understanding of drivers and motivations for the energy transition in energy communities, more research needs to be carried out in understanding how energy information is perceived as a community. Understanding how common vision, goals, and objectives can manifest into action can help communities transition swiftly, democratically, and easily to a more sustainable community. Furthermore, understanding which parameters are perceived as important by communities to feel empowered, identify progress, gain trust, or profit or reduce cost or remove barriers can help policymakers to design policy interventions to aid the transition. Some new research has focused on eco-feedback-based implementation that can guide the energy community to be collectively more informed about their energy consumption (Peña and Jensen 2023). These implementations are critical for better interface design related to energy data visualization which arises when designing many smart energy devices, especially the ones with a digitally interactive screen such as household smart meters, centralized heat pumps, elevators, mobile interfaces for EVs, interfaces for energy storage solutions and energy charging stations, etc. For policymakers, it is recommended that the design of energy policy must include the aspect of energy justice, energy equity, energy access as well as transparency including energy economics. This brings us to question, if community-level indicators may help us understand how energy information is perceived from a community perspective (Kumar et al. 2023, 2022), which can then guide policymakers to identify areas that require more focus and aid for transitioning.

Open RQ-2: how can energy interfaces aid in transitioning energy communities?

Interfaces play an important role in decimating information. However, new-age energy systems require that traditional sources of disseminating energy information such as pamphlets, and advertisements (Klein et al. 2023), etc. are augmented with digital technologies such as mobile-based applications that allow, switching energy service providers digitally or controlling energy systems and providing energy information (Idries et al. 2022; Peña and Jensen 2023). New age tools such as AR/VR-based devices, IoT, and blockchain-enabled applications have widened the scope of interaction possibilities between energy technology and energy citizens. This opens a rarely explored area in energy informatics. For businesses involved in the domain of energy, this provides a new unexplored market of catering to the more sustainably informed customers using digital tools and visualization that provides more community-centric information and helps transition to more sustainable energy usage such as converting outdated heating equipment running on natural gas to one which runs on green electricity (Koning et al. 2020). For policymakers, this allows them to mandate certain information must be provided on such community interfaces that could be part of public infrastructure such as EV charging stations or energy storage units. This could lead to the standardization of energy information and energy interfaces, bringing in wider adaptability due to being ubiquitous.

Conclusion

In conclusion, it can be said that Energy Informatics, over a decade, has seen tremendous growth in research interest and has proven to be quite effective in accelerating the transition to renewable energy resources.

This brings us to the main finding of the paper, which contributes to *identifying energy information themes relevant to stakeholders in the energy transition journey* as well as *energy information needs among stakeholders which establishes a clear interconnect with energy citizenship*.

From Table 5 it is clear that energy informatics and energy citizenship are greatly interlinked together, and certain themes are more prominent when stakeholders interact, however, this interaction is not limited to the themes identified in this paper as these are identified based on literature considered and there could be other potential interconnect between stakeholders that may not have been discovered during this research. Additionally, there may be other themes that may have an impact on how stakeholders interact which may not have been considered in this paper. Thus, the themes outlined in Table 5 cannot be considered the most exhaustive list of themes that are relevant. Still, this research helps to identify the different EI and EC themes that can be used by energy companies, researchers, and policymakers while interacting with different stakeholders to identify the most common energy information needs that can then be provided through research, product, or policy. For example, policymakers can use this research to mandate what energy information should be provided in new EV vehicles and mobile applications that may be used to control them. Similarly, EV companies can use this research to identify interface requirements that can make EV vehicles more energy efficient as well as help users be informed about the economical, technical, or legal aspects of using an EV vehicle.

Abbreviations

ACM	Association for computing machinery
BI	Building informatics
CO_2	Carbon dioxide
CTP	Community transition pathways
DR	Demand response
EI	Energy informatics

EC	Energy citizenship
ExC	Exclusion criteria
EV	Electric vehicle
Gt	Gigatons
ICT	Information and Communication Technologies
IEEE	Institute of Electrical and Electronics Engineers
IIT	Indian Institute of Technology
InC	Inclusion criteria
IoT	Internet of things
ML	Machine learning
RQ	Research question
SLR	Systematic literature review
SQ	Search query

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Author contributions
AK: The first author was responsible for the conceptualization, execution, and documentation of this systematic literature review. In the writing part, the first author took the lead in writing down the finding of this systematic literature review as well as creating the diagrams and tables presented in the paper. BN: The second author Bilal ensured the formulation of overarching research goals, and the rigor of the methodology for conducting the research and supported the documentation of outcomes including contribution in both writing as well as review and editing. AW: The third author Annika supervised the entire process with inputs in conceptualization, methodology, supervision, writing, review, and editing. All authors read and approved the final manuscript.

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Availability of data and materials
Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Declarations

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Not applicable.

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