Energy Research & Social Science 120 (2025) 103920

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

Local energy autarky: What it means and why it matters

Imad Antoine Ibrahim *, Franziska Baack, Ewert Aukes, Lisa Sanderink, Frans Coenen, Florian Helfrich, Athanasios Votsis, Thomas Hoppe

Section of Governance and Technology for Sustainability, Faculty of Behavioural, Management and Social Sciences, University of Twente Drienerlolaan 5, 7522 NB Enschede, the Netherlands

ARTICLE INFO

Keywords:
Energy autarky
Local communities
Local energy systems
Community energy
Microgrid

ABSTRACT

The concept of energy autarky, namely self-sufficient energy production and consumption, gained traction as states and other actors seek alternatives to centralised energy systems and conventional energy sources. This led to discussions about the potential for achieving autarky at various territorial levels, including national, regional, local, and even city district or household. While studies on autarky at the national level exist, the connotations of autarky at the local community level remain underexplored. This paper addresses this knowledge gap by exploring the connotations local communities and stakeholders attach to the state of autarky in local energy systems. Five connotations are identified from the literature, illustrated and reflected upon using a multiple-case study research approach, with six illustrative cases from Denmark, the Netherlands, and India. Results show that energy autarky is a context-dependent concept and that local community members attribute different connotations to it, some of which overlap. Additionally, challenges to autarky in local energy systems follow from local contextual conditions, leading to varying degrees to which communities achieve or even pursue autarky.

1. Introduction

Countries have discussed the pursuit of energy self-sufficiency for decades. Debates shifted from energy security [1] and independence [2–4] towards decentralization, namely the distributed and localized production of energy [5–7], as part of the sustainable energy transition based on distributed generation of renewable energy. Increasing energy autarky, namely self-sufficient energy production and consumption without any external support or intervention [8], is not just a normative goal of the energy transition but also an observable positive outcome of innovations in renewable energy technology [9–13]. Self-sufficiency refers to the focus on meeting local needs through local production is prioritized, rather than striving for complete self-sufficiency in all aspects of demand. Autarky comes with many assumed benefits. In theory, an autarkic energy system boosts production and employment due to the requirements for building and maintaining infrastructure, distributing energy resources, and implementing efficiency measures [8]. It can also lower energy cost during global scarcity events due to independence from the global energy market [14]. Autarky of energy systems often includes citizen initiatives aimed at localizing significant portions of the energy supply chain, including generation, distribution, supply, and consumption [8]. This localisation takes place at different levels, from regional, local, neighbourhood to street-level energy systems. One expression of these local more autarkic energy systems are energy communities that pursue a local energy system in which the assets are at least partly owned by the community and not by utilities or a commercial company. In addition, these communities pursue (semi) autonomy from the central electricity grid, with self-sufficiency being a key value [15–17].

This self-sufficient localisation of energy systems through energy communities is being pursued by the European Union (EU) and internationally with the hope that it will significantly contribute to the decarbonization of the energy system [18,19] as well as enable widespread energy access [20]. However, energy communities remain a niche phenomenon and their potential for scaling up remains limited [18,19]. Despite the increasing body of knowledge, significant gaps persist in the literature regarding the implementation of autarky at the local community level. A notable deficiency is the lack of information on local attitudes and willingness to adopt autarky [21]. Some contend that local autarky is feasible when citizens have a desire for achieving grid independence, local control, and energy security while having greater environmental benefits [22–24]. While considerable research has been conducted on why *nation states* may pursue energy autarky [25–27], the connotations local stakeholders attach to localizing their energy systems

* Corresponding author at: University of Twente, P.O. Box 217, 7500 AE Enschede, the Netherlands.
E-mail address: i.ibrahim@utwente.nl (I.A. Ibrahim).

https://doi.org/10.1016/j.erss.2025.103920
Received 12 June 2024; Received in revised form 21 December 2024; Accepted 6 January 2025
Available online 11 January 2025

towards autarky remain largely unexplored despite the increasing studies on the application of energy autarky locally [15,28]. This knowledge gap contributes to the lack of progress with scaling localized self-sufficient energy systems and limits the autarky concept's contributions to these efforts.

In this paper, we use the term "connotation" as defined in linguistics, semiotics, anthropology, and communication science to refer to a specific dimension of the meaning of, e.g., a term, concept, policy goal, or physical object. Connotation refers to additional layers of meaning that extend a term's literal or "face" value into culturally formed and often symbolic or ideological contents [29,30]. In our context, a focus on the connotative component of meaning highlights that energy autarky in a community is more than its literal definition (e.g. the ratio of self-produced energy). Energy autarky, as a goal and idea, takes on additional layers of connotative meaning that concern a wider set of values, beliefs, motivations, and processes, *as defined* by that community. While the core literal meaning of energy autarky may be stable across energy communities, its additional connotations will vary. It is thus important to unravel the diversity of energy autarky connotations across energy communities, especially since it has been shown that a community's connotations about a term, although they may appear meaningless or arbitrary to external observers, have a strong effect internally on that community, influencing social dynamics, behaviours, and actions [31,163].

This paper aims to bridge this knowledge gap by exploring connotations local communities and stakeholders attribute to the state of autarky of their local energy system. Communities prioritize different connotations for pursuing such shifts towards autarky [21,32–35]. One example is the different connotations communities place on the development of autarkic energy systems, which range from environmental concern to social norms, and personal gain [34]. To investigate these connotations, the paper answers the following research question: *What does energy autarky connote in local energy systems, when reflecting on it from selected real-world cases?* We employ an exploratory and multiple case research approach using six illustrative cases of local energy communities that seek to transition away from centralised energy systems and adopt some form of energy autarky.

In Section 2, we provide the conceptual background on the conceptualisation of energy autarky and identify five connotations of energy autarky or decentralization. These five connotations are not exclusive. Next, we present the research design and methods in Section 3. In Section 4, we present the results of six real-world case studies that help us to reflect on the connotations for local energy autarky as distinguished in Section 2. We then discuss these against relevant ongoing academic debates in Section 5, and conclude with suggestions for future research, and recommendations (Section 6).

2. Conceptual background

In this section, we first present our conceptualization of energy autarky in the context of this research and then provide five different connotations of autarky we identified in the literature.

2.1. Energy autarky

The concept of energy autarky has been defined in various ways [8,26,36–39]. In the context of this research, it refers to communities sustaining themselves using their own energy sources without importing energy from elsewhere [8]. Operationally, it involves establishing a decentralized energy system, enhancing energy efficiency, and increasing the generation and use of (renewable) energy. Energy autarky can be achieved at various levels, including household, neighbourhood, district, city, regional, or national level and may be absolute, with no imported energy, or relative, which involves balancing energy needs across sectors and seasons where in certain instances higher consumption costs were incurred [36,37]. Thus far, energy autarky has mostly been studied in a nation state or even geopolitical context [26,39–44]. Its importance on a supra-national scale resulted in recommendations for Europe to develop either an interconnected or fully renewable electricity system [26,39]. Various countries, such as Canada, Greece, Switzerland, and Zimbabwe, pursued national energy autarky to achieve political priorities, geopolitical aspirations, societal pressures and energy security. These efforts were hindered by several factors, primarily a lack of expertise and the inability to achieve societal consensus on energy-related issues [41–44].

More recently, there is increasing scholarly attention to energy autarky playing out at the regional and local level. The local level here refers to the level of local governments or below, namely city, district, village, neighbourhood, street, or household level where implementation takes place. At the local level, energy autarky describes locally produced renewable energy that provides energy services within the local community. The pursuit of local energy autarky comes with both advantages and disadvantages. Assumed benefits include increased energy security, which positively affects the local/regional economy, environment, and community well-being as well as increased independence from centralised energy systems, control, and thereby (political) power/coercion. Conversely, local energy autarky can be costlier, potentially less stable [26,45], and difficult to balance at times of peak supply or demand [46]. Regarding the viability of municipal energy autarky, challenges emerged due to the complexity and density of urban energy systems considering the impact of interpersonal dynamics and the local socio-cultural context on business models [33]. Thus, decision makers assess the viability of local energy autarky before supporting local initiatives in favour of adopting autarkic energy systems, considering factors such as macroeconomic impact, power grid compatibility, technical feasibility, and social implications [47]. Experiments at the neighbourhood level exploring the feasibility of autarky identified important local factors such as participant numbers, trust levels, and energy supply reliability [37,38]. Given the challenges, local communities can choose to become fully or partially autonomous from external (incumbent-led) energy systems, and to rely partially or entirely on local energy resources and infrastructures of their own [48].

In the local energy system, various actors play a role in achieving energy autarky, including businesses, government, potentially a distributed system operator, as well as civil society organizations, by harnessing the opportunities presented by renewable resources, thus facilitating energy governance at the local level [15]. Consequently, there is a growing call to strengthen efforts locally [28]. For example, in response to the need for resilient local energy supplies [49] and support for the grid through flexibility services like demand response [50], local activists are launching energy initiatives where the success of a transition largely hinges on shared visions, organizational frameworks, and the specific activities undertaken [15,51]. Households are also producing more and more of their own energy supply and this distributed generation is associated with increased autarky as well driven by the emergence of new motivations [23]. Local knowledge and networks are utilized to develop solutions that account for physical, technical, economic, and cultural factors and their interaction with other levels [34,51].

In this article, local community refers to a group of people living together in a specific geographical area, from a collection of houses to a district, sharing resources, a sense of place, identity, or values [10,48]. This concept applies to communities of various sizes, including villages, municipalities, small districts within cities, and groups of employees at a university. The examples provided encompass both developed and developing countries. The authors do not focus on the differences between cases, as their goal is to highlight the occurrence of energy autarky across various community scales.

2.2. Five connotations for autarky in local energy systems

We identified five connotations that communities and stakeholders in local energy systems, namely decentralized rather than centralised energy systems [50], ascribe to energy autarky: 1) (un-) availability of grid connections; 2) (un-) reliability of grid connections; 3) (un-) affordability of energy technologies; 4) (in-) dependence from the centralised energy grid; and 5) stress on the grid. The following sections elaborate each of these connotations. These connotations are interconnected and often overlap in practice. However, we present them separately to provide greater clarity.

2.2.1. (Un-)availability of grid connections

Energy autarky provides an alternative conceptualisation of achieving universal electricity access by 2030, a key target of the Sustainable Development Goals (SDG), namely SDG7 [52]. Improvements have often involved extending the electricity grid through increasing use of fossil fuel sources, which requires substantial investment and considerable time to build the necessary infrastructure [53]. As a consequence, the rate of progress in achieving this goal varies widely; Latin America has made greater advances compared to Sub-Saharan Africa, for instance. This disparity is also evident between urban and rural areas, with greater access for urban populations. By 2030, the majority of those without electricity are expected to be in the least developed countries and regions affected by conflicts and fragility [54]. Additionally, the pace of grid expansion has not kept up with rising demand [55], and population growth has exceeded the rate of infrastructure development [11]. Governments face challenges in planning, financing, and developing power infrastructure due to a lack of effective policies, inefficient governance, and inadequate tax revenue [56,57]. These challenges are particularly acute in the global South, including in regions like the Caribbean, where geographical dispersion across numerous islands complicates efforts [32,35]. In such cases, autarky emerges not as a deliberate goal but as a side effect of geographic and socioeconomic circumstances and a solution to provide energy access.

2.2.2. (Un-)reliability of grid connections

Autarky provides an alternative course of action when access to a functional grid does not necessarily ensure reliable electricity despite its importance for modern life [53,58]. Many regions across the world experience unstable and weak power supply [53], leading to intermittent energy service provision [59] and frequent outages, often totalling numerous hours on a monthly base [60]. Despite ongoing efforts to address these issues [61], reliable electricity supply remains a significant concern [62,63]. The situation is particularly severe in the Global South, where unreliable electricity supply results in power outages, adversely affecting residents. This has spurred the growth of alternative electricity sources like diesel generators [64], along with the use of kerosene, candles, and dry cell batteries [65]. More recently, households are turning to renewable options such as solar energy [66]. The unreliability of electricity supply leads to substantial economic losses, particularly impacting critical sectors like healthcare and education [67]. This issue often stems from among others inadequate generation capacity [68], as well as operational inefficiencies [69]. Rural communities are especially disadvantaged, lacking essential services crucial for economic development and quality of life improvements [70]. They suffer from the limitations of conventional electricity models, which have achieved only limited success [71]. Hence, in these communities, autarky is similarly not considered a deliberate goal, but an alternative way of achieving or improving secure energy supplies.

2.2.3. (Un-)affordability of energy technology

Investments in autarkic energy systems are also accompanied by different financial and economic considerations. Institutions face challenges in maintaining low energy prices [72], leading to demands for a societal transformation in energy provision [73]. High costs and insufficient financial capital hinder the establishment and reliability of energy grids [59,74], particularly to populations in developing nations [75]. In remote and rural areas, expanding the conventional grid is more costly than implementing independent renewable energy solutions. Additionally, many areas lack a sustainable business model for the operation and maintenance of these grids [76]. This issue is exacerbated by energy poverty, where high energy expenses coincide with low household incomes [10,77,78]. Ensuring affordable energy is a crucial goal across both the global North and South [79]. To address affordability, communities are increasingly investing in local energy projects [10,80]. The installation of modern, high-tech energy systems requires substantial financial outlays. These systems, which increasingly include smart technology, necessitate significant initial investments but aim to minimize energy use while optimizing energy consumption [80–84]. While these technologies are still under development and are considered costly, they offer potential for communities to become more self-reliant in their energy production and management [85–87]. Without external support, however, many households find these advanced solutions unaffordable. This is why regulatory and policy frameworks are developed to assist policymakers in promoting affordable technologies [88]. In sum, economic and financial contexts often play a crucial role in choosing an autarkic energy system. Either in the way of being a more economically viable option to ensure access to energy for all, or in the way of rethinking business models for the benefit of more environmentally sustainable technologies.

2.2.4. (In-)dependence from the centralised energy grid

Citizens pursue autarky and energy grid independence for various reasons including environmental, economic [9], social [89,90] and other normative considerations [91]. They include the desire to create sustainable energy systems following current trends towards decarbonization, digitization and decentralization [92–95]. Stand-alone systems are already in place for some remote locations with distance from the grid [96], using wind and solar energy [97]. Depending on the combination of energy sources, these autarkic systems can provide flexibility [98]. In such systems, consumers become prosumers, namely producers and consumers at once, and new governance models emerge [99]. People also consider this a form of self-governance which ensures access to flexible, sustainable, and resilient energy supply [100]. Nonetheless, such involvement from citizens and communities overall is not always easy, given the complexities surrounding the governance of energy systems [101]. The social organization of the community and the households in terms of visions, trust, social norms, concrete goals, and continuous communication are considered important factors affecting a successful transition from the grid [15,21,102,103]. Therefore, the optimal choice often appears to be maintaining a connection to the grid, minimizing reliance on it [104], while combining the use of various renewable energy sources [97], yet in a very coordinated manner [105]. In such contexts, autarky is seen as a deliberate goal, often linked to a wider motivation to “do good”.

2.2.5. Stress on the grid

Autarky also provides a solution to new problems due to the energy transition. Once established, power grids often remain unchanged due to the demands of long-term planning, extended construction periods, and their inherent complexity [106–108]. However, traditional power grids are aging infrastructures overdue for replacement [109], especially due to changing energy supply and demand, such as private solar photovoltaic (PV) installations, Electric Vehicle (EV) charging at home and heat pumps. It is important to note that integrating renewable energy sources introduces variability, as the availability of wind and solar energy can impact the consistency of the electricity supply [110] despite pressure to increase their percentage in the electricity market [111]. Additionally, factors such as climate-related and environmental goals lead to an increase in renewable energy generation, novel business models and technologies [112], and the need to balance the supply and demand further compound these issues [113,114]. These factors collectively exacerbate the stress on the grid [115], underscoring the urgent need for transformation to enhance resilience [116] and reduce pressure, particularly where grids are operating at maximum capacity [117,118]. This phenomenon, so-called "grid congestion", describes the effects of household production of electricity and consumption behaviour on the local grid, exceeding the capacities of local transformers [119]. Under such conditions ensuring sustained power stability becomes its own goal [120]. However, some countries lack the necessary flexibility in planning and operations to effectively manage these pressures [121]. In this case, autarky can be seen as a technically more viable alternative to relieve grid pressure, with a broader aim to both secure supply and more optimally use renewable sources.

3. Research design and methodology

This study follows a qualitative, multiple case study approach [122]. This approach allowed us to situate the five conceptual autarky connotations presented in Section 2 in six empirical cases. Based on data generated through desk research and semi-structured interviews we illustrate how different connotations of autarky play a role in a variety of social contexts [123]. First, we relate how we selected the cases and what their general characteristics are, followed by a description of the applied data collection and analysis methods.

3.1. Case selection and descriptions

All six cases were part of an EU funded research and implementation project. They all represent cases of (socio-)technical innovation in local energy systems and were identified based on their relevance and degree of access to data [124] The goal of studying these cases is to capture many different autarky connotations. This difference stems from the geographic location, the scale, and the socio-economic context of the cases. They are located in the Netherlands, Denmark, and India, i.e. the Global North and Global South, and range from including municipalities, small communities, and villages. This way, we show the range of autarky considerations in a wide variety of socially-situated contexts [125]. It is to be expected that autarky means something else everywhere and that different connotations are emphasised due to cultural, socio-economic, and political differences [126]. Nevertheless, the insights of this exploration contribute to a configurational definition of energy autarky that even avoids the blind spot of focusing on either Global North or Global South only [127].

Barubeda Village: Located in Jharkhand, India, the village consists of approximately 50 households. It is nestled between the Subarnarekha and Kharkai rivers, surrounded by agricultural land and forests. Residents lack access to public transportation, domestic water supply, and electricity. This community relies heavily on external resources, with no existing infrastructure to supply water and electricity or treat wastewater. Most buildings are residential, with an average density with primary energy use for domestic loads. The village does not have formal clubs or associations, and governance networks are minimal, covering few actors or organizations. An energy committee was recently established. Residents primarily use firewood for cooking and kerosene lamps for lighting. The nearest road is three kilometres away from the village, with no access to public transportation. Annually, many villagers migrate to the nearest city for several months to work [128].

Borakhai Village: Located in Assam, Eastern India, near Silchar and west of the Barak River, the village is surrounded by a built environment and agricultural lands, predominantly consisting of residential buildings with average density. The transportation and domestic water supply systems are both limited and unreliable. The organizational structure of the community remains unclear despite the presence of two energy committees. Development of energy infrastructure is feasible due to the average building density. However, the village lacks systems for water access, electricity, and wastewater treatment. Additionally, insulation materials and heating systems are absent [128]. Moreover, the transportation system is both limited and unreliable [129].

SlimPark Living Lab: The University of Twente (Enschede, The Netherlands) together with business companies and several knowledge institutes, are experimenting with autarkic approaches in the "SlimPark Living Lab". Located on the university campus, this facility serves as a small, self-sufficient EV charging station that can function without the grid connection by self-consuming the electricity from PV and battery electricity. It features a 27 kW solar panel rooftop and battery storage, configured as a carport rather than a closed building, and offers nine charging spots. The university owns and operates its own grid. However, it faces net congestion problems. Researchers use this living lab to study self-sufficient energy systems and user interactions [128].

Aardehuis Community: Located in the municipality of Olst-Wijhe, the Netherlands, a local community developed an estate which is made up of 23 individual homes and a communal building [130]. It was founded by environmentally conscious citizens via collaborative agreement in 2008 and is largely self-built. Residents organize themselves in an association, collaborate, and progressively acquire new skills [130–134]. The community is motivated by ideological beliefs rather than financial incentives [38]. It shows a strong degree of trust, social cohesion, and unified views on sustainability, shared infrastructure, and citizen engagement within the neighbourhood. This objective stems from a community-wide commitment to the circularity of resource production and consumption, aiming to rely exclusively on renewable energy sources for household needs. These elements focus on achieving greater sustainability in the daily practices of both individual citizens and the community as a whole [130–134].

Vriendenerf Community: Vriendenerf Community is located in the municipality of Olst-Wijhe, the Netherlands. The community estate comprises twelve homes and a common building. The original concept was to establish a community for senior citizens aged 55 and older, living in energy-efficient homes and sharing amenities, including a large garden and a communal building. Since its construction began in 2016, the community has been organized as an owners' association. The homes in Vriendenerf were constructed to nearly zero-energy standards to meet all energy requirements through onsite production from renewable energy sources. This was accomplished through a mix of energy efficiency measures and renewable energy generation facilities, including heat pumps and PV installations [135–138].

Skanderborg Municipality: Skanderborg, a small municipality in Denmark's Midjylland region southwest of Aarhus, has a population exceeding 60,000 across approximately 400 km^2 [139]. The local government is committed to advancing sustainability, particularly in climate and energy policies [140]. Moreover, its citizens recognize the critical need to address environmental issues [141] considering that Denmark has been a frontrunner for district heating and already established heat networks in its more densely populated areas. However, in more rural areas, these networks are not feasible, as they require a minimum of 250 houses per village.

3.2. Data collection and analysis

Data were collected from January 2022 to April 2024, utilizing desk research and semi-structured interviews. First, we collected available documentation for all cases, including plans and websites on the communities, their activities, municipal plans and policies around sustainability, project reports and others. Second, we conducted semi-structured interviews to obtain qualitative insights into the connotations attached to energy autarky across the cases. Interviews are particularly appropriate for accessing individual understandings and meanings in energy research and social science [142], which we aim for in terms of connotations of energy autarky. In total, twelve interviews were conducted with experts, stakeholders and practitioners linked to the EU funded research and implementation project described in Section 3.1 (see Table 2 for the list of interviewees). The interviews were conducted online, via Microsoft Teams, in English, while using auto-transcription except for one interview, which took place in person (in Dutch, for the Vriendenerf case in The Netherlands). The interviewees were asked about their motivations and incentives to participate in an autarkic energy system (see Table 3 for guiding questions). The interview questions also explored individual and shared goals, interests and values within their respective communities when it comes to energy autarky. Although the interview questions differed slightly across the cases to account for different contexts, all questions were formulated in an open-ended and singular manner without presuppositions in order to retrieve detailed answers, reduce bias, and leave room for follow-up questions and responses [143].

Finally, the data from the desk research and semi-structured interviews were combined to generate detailed case descriptions, structured according to policy levels (national level – municipal level – demonstration pilot project level) and themes such as known influential regulations, urban planning characteristics, and actors and institutions involved. These case descriptions were the subject of qualitative data analysis, specifically, we applied an abductive approach common for exploratory studies [144]. It enabled an iterative process for refining the five connotations as described in Section 2.2 as new data emerged from both data collection methods. The result is a comprehensive overview of varying connotations of energy autarky from the interviews, linked to case-specific policy and planning characteristics as identified with the desk research. Nevertheless, it is important to note that a case study approach combined with desk research and semi-structured interviews has certain limitations. While our study provides insights into connotations in India, the Netherlands and Denmark, the findings cannot simply be generalized for other countries or even for other regions within these three countries, because connotations such as those of autarky studied here are situated in the particular social contexts. Although we can formulate expectations in countries with similar characteristics, to continue developing the conceptualization or types of energy autarky. Moreover, with interviews as one of the primary sources for data collection, we relied on the availability of interviewees for detailed insights. While the EU funded project provided access to knowledgeable and representative respondents, there remains an inherent risk that the findings are limited by the scope and perspectives of the participants involved.

4. Results

The five connotations that local communities and stakeholders attribute to the state of autarky of their local energy system resulting from the multi-case data analysis are presented below (see Section 2.2).

4.1. (Un-)availability of grid connections

In contexts without access to the electricity grid, autarky takes on a different connotation. The case of the village of Barubeda illustrates this as it lacks connection to any major grid. Local energy provision relies primarily on imported firewood and kerosene due to the prohibitive cost of extending grid infrastructure to the few households in the steep valley. As part of a collaborative EU-India funded research project, an off-grid integrated energy system utilizing local renewable sources was developed and deployed. Given the absence of local energy capacity, the project includes the installation of lightweight wind turbines and solar panels for energy production, coupled with battery storage. The plan features seven wind turbines, and a PV system which is installed but was not yet operational at the time this research was conducted. The battery storage installation was prepared and scheduled for completion in 2024. The plan was that households would be connected to a microgrid with autonomous internal distribution, linked to the locally produced energy. This would also power e-rickshaws and a water system, ensuring 24/7 electricity for basic usage [128,129]. This case underscores the absence of grid connectivity, which has left Barubeda without electricity, and highlights efforts to establish an off-grid, renewable energy system. In other words, the autarkic energy system developed for the village did not emerge as a deliberate goal, but to offer a solution to the geographic and socioeconomic contexts that prevent the village from having a secure grid connection and reliable access to energy.

4.2. (Un-)reliability of grid connections

When electricity provision is intermittent rather than continuous, autarky also takes on a different connotation. In the case of the East-Indian state of Assam, near Silchar, the village of Borakhai is only partially electrified, receiving electricity for just a few hours each day. Energy consumption is primarily for domestic use. Residents mainly use firewood for cooking and kerosene lamps for lighting, although some households have access to liquefied petroleum gas. The village suffers from a weak and unreliable grid connection, with some homes receiving less than 200 W, while others get 0.5 kW for about a third of the day. The community is eager to improve their energy infrastructure to secure reliable 24/7 access and is participating in a pilot project focused on the development and management of a local off-grid energy system, both on the short and long term [145]. The initiative currently covers forty houses in two sections of the village [146]. Borakhai has been identified as an ideal location for testing a hybrid, sustainable, renewable energy system, considering socio-economic and environmental factors [147,148]. The project aims to establish an off-grid system that utilizes solar, wind, and biogas energy, supported by battery storage. To conclude, the autarkic energy system developed in Borakhai is motivated by a desire to have more reliable electricity. There is a connection to the (unreliable) grid, but the autarkic energy systems can be seen as an alternative or complementary way to improve energy security for the villagers.

4.3. (Un-)affordability of energy technology

Affordability plays different roles for the connotations attached to autarky in different contexts. We illustrate these differences using several cases. In the Vriendenerf case, there was intense discussion at the beginning of the project, whether the community preferred the more expensive, but more sustainable heating solution using ground heat pumps over a cheaper alternative. In the end, the community decided to spend more money and eventually managed to recover the investment, partly because of the high energy price in recent years. In the Aardehuis case, the community battery connected to the solar car park would not have been possible without investments from an EU funded project. At the time the research was conducted such batteries were still too expensive to be affordable without some form of external financial support. These two cases highlight autarky as a luxury and an ideological goal these communities strive for, even when additional costs are attached to it. While the communities in the Indian cases could not have afforded the technological interventions and new infrastructure without government funding, these interventions were still the most affordable option to provide electricity for all. Extending or upgrading the larger grid would have been much more expensive. In these contexts, the autarkic options become the only financially viable ones. Lastly, ownership of a building also plays a big role in investment decisions. In the case of the Danish municipality of Skanderborg, rental housing units are renovated with a smart energy system [149]. The landlords of these housing units made the decision to modernize despite of facing the split incentive problem. Hence, these three illustrative cases show that decisions upon autarky can also be connected to economic and financial contexts. Whether additional (external) investments were the deciding factor or not, autarky in all three cases required a novel way of perceiving costs and benefits.

4.4. (In-)dependence from the central energy grid

As touched upon in the previous section, autarky can take on an ideological connotation, where grid-independence becomes its own goal. In the case of the community of Aardehuis, although there is a high degrees of citizen engagement, well established technical infrastructure and shared community cohesion and consensus, two factors are currently negatively impacting the endeavours of the community towards becoming autarkic. Firstly, the community's energy infrastructure still shows limited energy production during winter months, thus a dependence on energy from the main grid remains. Secondly, even though the community has a national exemption from the Dutch national government's legal requirements (i.e., from the Electricity Law), granting them the opportunity to experiment with alternative grid designs and forms of local energy generation, completely disconnecting the geographical area where the community resides from the main electricity grid (i.e., regarding production, management and physical infrastructure) is not allowed. As illustrated in this case, the connotations energy communities ascribe towards energy autarky are multifaceted. Shifts in the forms and newfound possibilities of local energy generation and management can lead to an increased desire of neighbourhoods to organize themselves, which might eventually become completely independent of the main grid, if they have established sufficient technical infrastructure, practices, and social arrangements within their community. This desire towards autarky could stem either from a community's ambitions towards reducing their carbon emissions or becoming fully carbon-neutral, and through this eventually achieving the possibility of becoming an autarkic neighbourhood, or it might in some cases be based on a notion of independence from centralised energy infrastructures in itself [130–134,150]. Clearly, in the community of Aardehuis, autarky is a deliberate goal to increase the local community's degree of self-sufficiency. This is linked to a broader goal to "do good", which – in fact – is the foundation for the cohesion in Aardehuis. However, this case also shows that this connotation of autarky can be obstructed by technical feasibility and regulatory issues.

4.5. *Stress on the grid*

Lastly, autarky can take on an instrumental connotation. The case of

Table 1
Overview of the main insights from the cases presented per identified connotation.

Cases & characteristics	(Un-) availability of grid connections	(Un-) reliability of the grid connection	(Un-) affordability of Energy Technology	(In-) dependence from the grid	Stress on the grid
Barubeda - 50 household without grid connection - Prevented by high costs and location in steep valley - Off-grid energy system	- Autarky not a deliberate goal - Addresses socio-economic and geographical contexts - Goal: energy access		- Autarky not a deliberate goal - Presents an affordable option to energy access, as opposed to a grid connection		
Borakhai - Residential area, only partly electrified due to unreliable grid connection - Community eager for 24/7 electricity supply - Off-grid energy system		- Autarky not a deliberate goal - Presents an alternative to existing infrastructure - Goal: energy security	- Autarky not a deliberate goal - Presents an affordable option to energy security		
Vriendenerf - 12 homes for senior citizens with net-zero aim - Financial implications of energy options discussed - Chose more expensive but more sustainable heating solutions			- Autarky a deliberate goal - New ways of (looking at) financing energy systems - Goal: environmental sustainability		
Skanderborg - Municipality of 60,000, local government pursues sustainability - Landlords were faced with split incentives - Despite this, housing units are renovated with smart energy systems			- Autarky a deliberate goal - Renders new ways of (looking at) financing energy systems - Goal: environmental sustainability		
Aardehuis - Earthship community, 23 homes, - Aim: self-sufficiency, and disconnecting from grid - External finance necessary for community battery, connected to solar car park - But due to poor performance in winter and regulations still connected			- Autarky a deliberate goal - Renders new ways of (looking at) financing energy systems - Goal: environmental sustainability	- Autarky a deliberate goal - Extends the idea of self-sufficiency - Goal: environmental sustainability *Connotation of autarky challenged by technical and legislative realities.*	
SlimPark Living Lab - Experiment on University campus to test a small, self-sufficient charging station - Designed to reduce grid pressure and more optimal use of renewables - Energy system installed of solar panel rooftop and battery storage as carport, and nine charging spots					- Partial autarky a deliberate goal - Technically viable alternative to reduce grid congestion - Goals: environmental sustainability, energy security *Connotation of autarky challenged by informational and human interactions.*

the SlimPark Living Lab showcases how autarkic integrated energy systems can alleviate grid stress in a situation of grid congestion in a controlled setting. Here, novel decentralized energy management technologies are evaluated to ensure a stable supply when renewable sources are scarce, and demand is high. However, the success of this approach hinges on the charging behaviour of EV owners. To assist them, the experiment included an app with an intuitive interface where EV owners first select a charging mode—Fast Charging (business-as-usual) or Solar Charging. If the latter is chosen, owners must input their expected departure time and approximate energy need. The energy management system then uses this data to better match supply and demand, thus reducing grid pressure and enhancing the system's autarky. Nonetheless, achieving complete autarky is challenging due to three socio-technical barriers [151]. The primary challenge is the absence of integrated communication between the EVs and the charging system regarding the vehicles' flexibility. The next challenge revolves around human interaction. Although most EV owners prefer Solar Charging, they often switch to Fast Charging if the system delays the start of charging. Moreover, the information provided by EV owners in the app is frequently inaccurate. Departure times are typically later than reported, and energy demand is overestimated, likely as a precaution. This suggests a limited understanding among EV owners about their vehicle's capacity and range. The SlimPark Living Lab tests an autarkic energy system as a technically viable alternative to reduce grid congestion. However, it also shows that this connotation of autarky can, in turn, be challenged by other factors, mostly notably human behaviour.

Table 1 presents an overview of the main insights that can be drawn from the cases illustrating the five identified connotations from Section 2 regarding local communities and stakeholders pursuing local energy autarky.

5. Discussion

Results show that meaning and to a larger extent connotation of energy autarky in local energy systems varies, and overlaps across cases, hence contexts. In line with previous research, the cases showed that decisions of a specific community or household to become autarkic typically hinge on specific perceived benefits of autarky [45]. The significance of each of the connotations central to this work - unavailability, unreliability, unaffordability, independence and stress of energy grid - can differ markedly from one community to another, influenced by local conditions, but also in terms of needs and aspirations of local communities and their members. For example, in the Aardehuis case, the local community decided to adopt a fully autarkic system to achieve independence from the grid and to foster a more sustainable lifestyle [130–134]. In Borakhai, residents pursue energy autarky to secure a reliable grid connection, which economically benefits the sale of their agricultural products [146]. In contrast, the Barubeda case showed that an off-grid integrated energy system based on renewables was developed to cope with the lack of access to the main electricity grid [128]. In summary, a key result from the study is that energy autarky should be seen as a context-dependent concept.

The cases also revealed that certain limitations should be considered when it comes to achieving full autarky. The SlimPark Living Lab case showed that becoming autarkic can be quite challenging. The smart EV charging system encountered problems due to technical protocols, and there was also a lack of trust and knowledge about the system among EV owners [151]. Hence, even if local energy autarky is desirable, it may be only-partly-doable. It is anticipated that hybrid energy systems, which combine traditional and self-sustaining sources, will emerge and likely remain prevalent. These systems integrate fossil fuels with renewables [152] and are considered superior alternatives to relying solely on conventional energy sources [153]. They are also seen as more practical and effective [154,155] and are considered a preferable choice for new energy grids due to their economic, environmental, and social benefits [156]. Often, these systems include battery storage to provide energy in off-grid settings [154]. While the long-term goal of the projects in these cases is to achieve complete autarky, hybrid systems may progressively reach higher degrees of self-sufficiency. However, achieving this state is not guaranteed and depends on various factors.

Varying degrees of autarky can be achieved based on biophysical conditions such as technological dependence, local renewable energy resources, settlement and building characteristics, and energy uses, as well as social-regulatory factors including social organization, regulations, values, and the extent of autarky aspirations [128]. These can be linked with for instance environmental impacts, climate change and the Anthropocene. The Aardehuis Community's success is attributed to their strong commitment both individually and collectively [130–134], although replicating this elsewhere may prove challenging without similar efforts. In contrast, the SlimPark living lab case exemplifies the potential for achieving autarky in a highly specific, small-scale environment [128]. The feasibility of replicating such success on a larger scale or in similar environments remains uncertain. The Indian cases of Barubeda and Borakhai became less autarkic due to their connection with a microgrid to the main electricity grid as they were not connected before [128].

Autarky comes with both pros and cons that need careful consideration, as more local communities consider becoming autarkic (to some degree), which could adversely affect individuals (i.e., community members individually [157,158]). For example, the Vriendenerf case shows that high personal investments are linked to implementing essential technologies, such as expensive heat pumps. Households must be able to afford the costs associated with connecting to the grid [159], despite the economic burden they must bear [160]. This affordability ensures that even the poorest individuals can access energy services without compromising their ability to purchase other essential goods [161]. Contrarily, the touted benefits of autarky include aspirations of stable, secure, affordable, and independent energy sources for communities and households [128]. The SlimPark Living Lab case highlights the need for careful assessment due to challenges encountered in establishing the system, despite its benefits, especially considering the project's scale [128]. Thus, the implementation of energy autarky can be considered as a double-edged sword, illustrating the complex relationship between energy and society [24,162].

Ongoing academic debates about implementing energy autarky at the local level tend to highlight community initiatives in countries such as the Netherlands, Germany, India, Poland, or Denmark [25–27]. This paper contributes to these debates by stressing that achieving autarky locally requires local communities being properly motivated. Without this motivation, these communities are unlikely to make the drastic decision to shift from relying on centralised energy grids to becoming self-sufficient through distributed generation using renewable energy sources. However, adequate means and circumstances must also be in place. For example, the Aardehuis and Vriendenerf communities, despite their ideological inclination towards energy autarky, could only pursue this goal because their community members on average, the residents had a high socio-economic status (i.e., were relatively wealthy) [130–134]. Moreover, the SlimPark living lab project would not have been possible without financial and organizational support and facilitation by a public university, which is committed to achieving sustainability goals [128]. These factors must be considered alongside the main connotations for pursuing local autarky, 1) (un-) availability of grid connections; 2) (un-) reliability of grid connections; 3) (un-) affordability of energy technologies; 4) (in-) dependence from the centralised energy grid; and 5) stress on the grid.

6. Conclusion

This paper sought to explore and reflect on the connotations local communities and stakeholders have regarding the state of autarky of their local energy system, using six illustrative real-world cases. Results show that there are basically five different connotations to autarky of local energy systems: 1) (un-) availability of grid connections; 2) (un-) reliability of grid connections; 3) (un-) affordability of energy technologies; 4) (in-) dependence from the centralised energy grid; and 5) stress on the grid. The cases highlight the presence of both pros and cons local communities encounter in their journey towards achieving energy autarky. The former includes the ability to have a secure and independent energy system, while the latter involves the high costs of such a shift. This raises the question whether energy autarky should be considered an ideal or rather a desirable state of local energy systems considering factors such as growing populations, the need for energy security and limited resources, geopolitical implications and economic costs. It also depends on whether a community is in a state of autarky unvoluntary or whether they are striving to reach it. A key finding from the analysed multiple case studies revealed that energy autarky should be seen as a context-dependent concept. Various connotations of energy autarky were observed in different cases, with variation from case to case, and cases where there was even overlap. It was also noticeable that the connotation seemed to be related to certain biophysical conditions, preferences and attributes of the local communities that live or work there. Moreover, the study also showed that deciding to adopt strategies or policies in favour of local energy autarky and related objectives sets a trajectory in motion that will last for years or even decades to come.

Like any other study, the present work has several limitations. First, there was an uneven spread of stakeholders in the interviews. Fewer experts, stakeholders, and practitioners interviewed in India. This might have caused selection bias in the results which should be considered when assessing them. Second, the theoretical perspective is constrained due to the focus on a new concept that has not been extensively analysed in the literature especially at the local level resulting in the exploratory nature of the research and absence of conceptual frameworks to be applied.

Since the concept of energy autarky is novel and lacks local-level assessment, there are many avenues for future research. This could be addressed by raising new research questions. For example, what would likely be the consequences of achieving autarky at the various levels be it local, regional, and national? And how will this affect political dynamics? What is the overall perspective of citizens in different countries on this topic? How would the implementation of energy autarky look in the Global South, and what motivates these nations to pursue it? How do various disciplines impact the application of energy autarky at different levels? For example, how do domestic and municipal laws influence this effort positively or negatively? Future research could further explore this topic answering these questions. For the time being, there is no clear indication whether fully autarkic energy systems are possible or even desirable. Hence, the move towards a more decentralized energy system does not necessarily mean the establishment of fully autarkic energy subsystems. Despite the popularity of this concept, one has to keep in mind that reaching energy autarky in practice across all scales may not yield the expected results.

The analysis leads to several recommendations. First, the implementation of energy autarky by local communities offers a possible pathway to energy independence and should be assessed as such by policy makers. This assessment should be conducted on a case-by-case basis, considering both general and specific contextual factors for each community. Second, various interventions and incentives, from financial to technical, could be considered if energy autarky is deemed suitable for a particular community. Examples include governmental subsidies for renewable energy technologies, and the relaxation of provincial and local regulations that create barriers to the establishment of self-sufficient communities. Third, local communities should carefully weigh the benefits and drawbacks of energy autarky before undertaking this initiative. Fourth, we suggest developing clear guidelines and regulations to support communities that want to become autarkic to address organizational aspects, energy production, consumption, and sales.

CRediT authorship contribution statement

Imad Antoine Ibrahim: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Franziska Baack:** Writing – review & editing, Writing – original draft, Resources, Methodology, Investigation, Formal analysis, Conceptualization. **Ewert Aukes:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Lisa Sanderink:** Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Frans Coenen:** Writing – original draft, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Florian Helfrich:** Writing – original draft, Methodology, Formal analysis, Conceptualization. **Athanasios Votsis:** Writing – original draft, Resources, Methodology, Formal analysis, Conceptualization. **Thomas Hoppe:** Writing – review & editing, Visualization, Supervision, Resources, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

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

Acknowledgment

The article has received funding for the SUSTENANCE project from both the European Union's Horizon 2020 research and innovation programme under grant agreement No 101022587, and the Department of Science and Technology (DST), Government of India. It also received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957682 for the SERENE project. Any results of these projects reflect only the research team's view, and the funding agencies and the European Commission are not responsible for any use that may be made of the information it contains.

Appendix A

Table 2
List of interviews per case.

Case	Interviewee role	Organization	Date
Skanderborg, Denmark	Climate coordinator	Municipality Skanderborg	16-10-2023
	Committee member	Sjelle heat committee	13-11-2023
	Project manager	Neogrid company	27-10-2023

(*continued on next page*)

Table 2 (*continued*)

Case	Interviewee role	Organization	Date
Olst-Wijhe, The Netherlands	Project manager Olstergaard project	Municipality Olst-Wijhe	14-11-2023
	Policy officer Sustainability and Renewable Energy	Municipality Olst-Wijhe	14-11-2023
	Community representative	Aardehuizen Association	19-10-2023
	Community representative	Vriendenerf Association	24-11-2023
	Researchers	Saxion University of Applied Science	03-11-2023
Barubeda, India	Female villager	n/a	07-02-2024
	Researcher	Indian Institute of Technology Bombay	
Borakhai, India	Principal Investigator	National Institute Of Technology Silchar	12-04-2024
Slimpark	Principal Investigator, Researcher	University of Twente	08-11-2023

Table 3
Guiding questions for interviews.

Questions
Name of the person answering the questions
Email address
Phone number
Consent to recording the meeting
(Use) Case
Which country?
Which specific (use)case? e.g., installation of x no. heat pumps in specific location, or new form of organization
Which person or organization is leading this process?
Collaboration
Which person or organization initiated the process?
Which other persons or organization participate in the process? Did the initial group of involved stakeholders change throughout the project's development?
Was this cooperation formalized?
If yes, how was the cooperation formalized? E.g., business contract, rental agreement, public-private partnership, etc. Is this formalisation being upheld? If not, what changed?
Results
What is the result of the process at this point in time? E.g., y no. of heat pumps installed, energy community initiated, etc. Which development steps (technical and social) have been achieved already? Were any of the planned steps disregarded or changed? If so, why?
Did this specific process have additional effects? E.g., interest from other neighbours in heat pumps, etc.
If yes, during which phase of the project did this effect occur? E.g., planning, construction, use Were there any delays with the development and implementation of changes?
Energy community
Is this (use)case part of an energy community? If so, how do you define energy community and why do you define yourself as such? If not, why not and how do you define the case?
If yes, which legal form does the energy community take?
Are citizens generally consumers or also producers of energy in the process? Are there any citizens of the community/neighbourhood not participating?
Citizen engagement
(How) were citizens involved in the process otherwise? Which, if any, development steps were citizen-led?
Which format? E.g., one-off meeting, continuous meetings, digitally, etc. (if different, for different groups, please specify)
What was the citizen engagement about? E.g., Information provision, consultation on decisions, collaboration on specific problems, etc.
What was the result of the engagement? E.g., a decision, a change of attitude, specific action points, a document, etc. Please provide any documentation.
How is the community represented in the project? Does the community feel adequately represented in the project?
Who is the spokesperson for the community? Does the community feel adequately represented by the spokesperson?
Social acceptance
In your opinion, did the project thus far change the level of social acceptance? If yes, please provide details. Can you point towards specific instances, events, people?
Are there any negative implications or unforeseen impacts/challenges?

(*continued on next page*)

Table 3 (*continued*)

Social acceptance
If the project were launched today, would you join it again? Would you do anything differently?
How do you see the future of the project and its development?
What kind of impact does this project have on your community in the long term?
Which changes/development steps have you planned for the future?
What new/recent debates about local (integrated) energy systems are ongoing at the societal level in Denmark/Netherlands/Poland and at the local level among relevant stakeholders?
Imagine for a moment that you collectively own and manage renewable energy in your community: its generation and usage.
How do you envision peer-to-peer interaction with your neighbours and the municipality—socially, technologically, but also through the design of your neighbourhood's spaces—to ensure fair and feasible sharing?

Data availability

Data will be made available on request.

References

[1] G. Bang, Energy security and climate change concerns: triggers for energy policy change in the United States? Energy Policy 38 (4) (2010) 1645–1653, https://doi.org/10.1016/j.enpol.2009.01.045.

[2] R.Y. Shum, Where constructivism meets resource constraints: the politics of oil, renewables, and a US energy transition, Environmental Politics 24 (3) (2015) 382–400, https://doi.org/10.1080/09644016.2015.1008236.

[3] L. Hughes, The limits of energy independence: assessing the implications of oil abundance for U.S. foreign policy, Energy Research & Social Science 3 (2014) 55–64, https://doi.org/10.1016/j.erss.2014.07.001.

[4] M.T. Nance, W.A. Boettcher, Conflict, cooperation, and change in the politics of energy interdependence: an introduction, Energy Res. Soc. Sci. 24 (2017) 1–5, https://doi.org/10.1016/j.erss.2016.12.020.

[5] A. Goldthau, Rethinking the governance of energy infrastructure: scale, decentralization and polycentrism, Energy Res. Soc. Sci. 1 (2014) 134–140, https://doi.org/10.1016/j.erss.2014.02.009.

[6] L. Lazaro, R.S. Soares, The energy quadrilemma challenges - insights from the decentralized energy transition in Brazil, Energy Res. Soc. Sci. 113 (2024) 103533, https://doi.org/10.1016/j.erss.2024.103533.

[7] M. Kubli, S. Ulli-Beer, Decentralisation dynamics in energy systems: a generic simulation of network effects, Energy Res. Soc. Sci. 13 (2016) 71–83, https://doi.org/10.1016/j.erss.2015.12.015.

[8] M.O. Müller, A. Stämpfli, U. Dold, T. Hammer, Energy autarky: a conceptual framework for sustainable regional development, Energy Policy 39 (10) (2011) 5800–5810, https://doi.org/10.1016/j.enpol.2011.04.019.

[9] S. Adams, D. Brown, J.P. Cárdenas Álvarez, R. Chitchyan, M.J. Fell, U.J. J. Hahnel, et al., Social and economic value in emerging decentralized energy business models: a critical review, Energies 14 (23) (2021) 7864, https://doi.org/10.3390/en14237864.

[10] B.P. Koirala, E. Koliou, J. Friege, R.A. Hakvoort, P.M. Herder, Energetic communities for community energy: a review of key issues and trends shaping integrated community energy systems, Renew. Sustain. Energy Rev. 56 (2016) 722–744, https://doi.org/10.1016/j.rser.2015.11.080.

[11] P. Alstone, D. Gershenson, D.M. Kammen, Decentralized energy systems for clean electricity access, Nat. Clim. Chang. 5 (4) (2015) 305–314, https://doi.org/10.1038/nclimate2512.

[12] I. Soutar, Dancing with complexity: making sense of decarbonisation, decentralisation, digitalisation and democratisation, Energy Res. Soc. Sci. 80 (2021) 102230, https://doi.org/10.1016/j.erss.2021.102230.

[13] J. Radtke, O. Renn, Participation in energy transitions: a comparison of policy styles, Energy Res. Soc. Sci. 118 (2024) 103743, https://doi.org/10.1016/j.erss.2024.103743.

[14] A. Walch, M. Rüdisüli, Strategic PV expansion and its impact on regional electricity self-sufficiency: case study of Switzerland, Appl. Energy 346 (2023) 121262, https://doi.org/10.1016/j.apenergy.2023.121262.

[15] T. van der Schoor, B. Scholtens, Power to the people: local community initiatives and the transition to sustainable energy, Renew. Sustain. Energy Rev. 43 (2015) 666–675, https://doi.org/10.1016/j.rser.2014.10.089.

[16] M. Tsagkari, J. Roca, G. Kallis, From local island energy to degrowth? Exploring democracy, self-sufficiency, and renewable energy production in Greece and Spain, Energy Res. Soc. Sci. 81 (2021) 102288, https://doi.org/10.1016/j.erss.2021.102288.

[17] J. Barnes, P. Hansen, T. Kamin, U. Golob, S. Darby, N.M. van der Grijp, et al., Creating valuable outcomes: an exploration of value creation pathways in the business models of energy communities, Energy Res. Soc. Sci. 108 (2024) 103398, https://doi.org/10.1016/j.erss.2023.103398.

[18] J. Blasch, N.M. van der Grijp, D. Petrovics, J. Palm, N. Bocken, S.J. Darby, et al., New clean energy communities in polycentric settings: four avenues for future research, Energy Research & Social Science (2021) 82, https://doi.org/10.1016/j.erss.2021.102276.

[19] D. Petrovics, D. Huitema, A. Jordan, Polycentric energy governance: under what conditions do energy communities scale? Environ. Policy Gov. 32 (5) (2022) 438–449, https://doi.org/10.1002/eet.1989.

[20] R.C. Beckett, M. Terziovski, Community-engaged renewable energy deployment: a strategic niche management perspective, Aust. J. Environ. Manag. 30 (2) (2023) 242–265, https://doi.org/10.1080/14486563.2023.2221205.

[21] B.J. Kalkbrenner, J. Roosen, Citizens' willingness to participate in local renewable energy projects: the role of community and trust in Germany, Energy Res. Soc. Sci. 13 (2016) 60–70, https://doi.org/10.1016/j.erss.2015.12.006.

[22] J.K. Juntunen, M. Martiskainen, Improving understanding of energy autonomy: a systematic review, Renew. Sustain. Energy Rev. 141 (2021) 110797, https://doi.org/10.1016/j.rser.2021.110797.

[23] M. Engelken, B. Römer, M. Drescher, I. Welpe, Why homeowners strive for energy self-supply and how policy makers can influence them, Energy Policy 117 (2018) 423–433, https://doi.org/10.1016/j.enpol.2018.02.026.

[24] R. McKenna, The double-edged sword of decentralized energy autonomy, Energy Policy 113 (2018) 747–750, https://doi.org/10.1016/j.enpol.2017.11.033.

[25] K.S. Bhat, J. Ganglbauer, M. Tragner, Self-consumption and energy autarky in energy communities – Simulation and evaluation of scalable 'Energy Cells' in Austria, Belgium and Norway, in: 2022 AEIT International Annual Conference (AEIT), IEEE, 2022, pp. 1–6.

[26] T. Tröndle, S. Pfenninger, J. Lilliestam, Home-made or imported: on the possibility for renewable electricity autarky on all scales in Europe, Energ. Strat. Rev. 26 (2019) 100388, https://doi.org/10.1016/j.esr.2019.100388.

[27] D. Pieńkowski, W. Zbaraszewski, Sustainable energy Autarky and the evolution of German bioenergy villages, Sustainability 11 (18) (2019) 4996, https://doi.org/10.3390/su11184996.

[28] C. McGookin, Ó. Gallachóir, B, Byrne E., An innovative approach for estimating energy demand and supply to inform local energy transitions, Energy 229 (2021) 120731, https://doi.org/10.1016/j.energy.2021.120731.

[29] T.A. Sebeok, M. Danesi, The Forms of Meaning: Modeling Systems Theory and Semiotic Analysis, Mouton de Gruyter, Berlin, New York, 2000.

[30] P. Cobley, The Routledge Companion to Semiotics, Routledge, London, New York, 2010.

[31] R. Barthes, Mythologies: The Complete Edition, in a New Translation, Hill and Wang, New York, 2012.

[32] A. Alegre-Bravo, Anderson C. Lindsay, Exploring the influence of multidimensional variables on access to electricity in rural areas of the Global South, Appl. Energy 333 (2023) 120509, https://doi.org/10.1016/j.apenergy.2022.120509.

[33] P.M. Bögel, P. Upham, H. Shahrokni, O. Kordas, What is needed for citizen-centered urban energy transitions: insights on attitudes towards decentralized energy storage, Energy Policy 149 (2021) 112032, https://doi.org/10.1016/j.enpol.2020.112032.

[34] A. Ghorbani, L. Nascimento, T. Filatova, Growing community energy initiatives from the bottom up: simulating the role of behavioural attitudes and leadership in the Netherlands, Energy Res. Soc. Sci. 70 (2020) 101782, https://doi.org/10.1016/j.erss.2020.101782.

[35] M. Dornan, Access to electricity in Small Island developing states of the Pacific: issues and challenges, Renew. Sustain. Energy Rev. 31 (2014) 726–735, https://doi.org/10.1016/j.rser.2013.12.037.

[36] J. Schmidt, M. Schönhart, M. Biberacher, T. Guggenberger, S. Hausl, G. Kalt, et al., Regional energy autarky: potentials, costs and consequences for an Austrian region, Energy Policy 47 (2012) 211–221, https://doi.org/10.1016/j.enpol.2012.04.059.

[37] F. Ecker, U.J.J. Hahnel, H. Spada, Promoting decentralized sustainable energy systems in different supply scenarios: the role of Autarky aspiration, Front. Energy Res. (2017) 5, https://doi.org/10.3389/fenrg.2017.00014.

[38] B. Homan, S. Nebiolo, G. Hoogsteen, J.L. Hurink, G.J. Smit, Improving the degree of Autarky of a 16 house neighbourhood in the Netherlands - a case study, in: 2019 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe), IEEE, 2019, pp. 1–5.

[39] F. Neumann, Costs of regional equity and autarky in a renewable European power system, Energ. Strat. Rev. 35 (2021) 100652, https://doi.org/10.1016/j.esr.2021.100652.

[40] T. Moss, M. Francesch-Huidobro, Realigning the electric city. Legacies of energy autarky in Berlin and Hong Kong, Energy Research & Social Science 11 (2016) 225–236, https://doi.org/10.1016/j.erss.2015.10.002.
[41] S. Arapostathis, Y. Fotopoulos, Transnational energy flows, capacity building and Greece's quest for energy autarky, 1914–2010, Energy Policy 127 (2019) 39–50, https://doi.org/10.1016/j.enpol.2018.11.022.
[42] Y.B. Blumer, C. Moser, A. Patt, R. Seidl, The precarious consensus on the importance of energy security: contrasting views between Swiss energy users and experts, Renew. Sustain. Energy Rev. 52 (2015) 927–936, https://doi.org/10.1016/j.rser.2015.07.081.
[43] A. Cheater, Issues of energy Autarky and interdependence among small-scale commercial farmers in Zimbabwe: chapter 10, in: M. Haswell, D. Hunt (Eds.), Rural Households in Emerging Societies: Technology and Change in Sub-Saharan Africa, Routledge, Taylor & Francis Group, London, 2020.
[44] T. Greenwood, Canada's quest for energy Autarky: chapter 3, in: J.C. Hurewitz (Ed.), Oil, the Arab-Israel Dispute, and the Industrial World: Horizons of Crisis, 1st ed., Routledge, New York, NY, 1976.
[45] F. Ecker, H. Spada, U.J. Hahnel, Independence without control: Autarky outperforms autonomy benefits in the adoption of private energy storage systems, Energy Policy 122 (2018) 214–228, https://doi.org/10.1016/j.enpol.2018.07.028.
[46] D. Newbery, Shifting demand and supply over time and space to manage intermittent generation: the economics of electrical storage, Energy Policy 113 (2018) 711–720, https://doi.org/10.1016/j.enpol.2017.11.044.
[47] M. Engelken, B. Römer, M. Drescher, I. Welpe, Transforming the energy system: why municipalities strive for energy self-sufficiency, Energy Policy 98 (2016) 365–377, https://doi.org/10.1016/j.enpol.2016.07.049.
[48] E. Aukes, I. Ibrahim, L. Sanderink, Y. Krozer, F. Coenen, Categorization of types of consumers: sustainable energy system for achieving novel carbon neutral energy communities, SUSTENANCE D3.5 (2023).
[49] J. Platje, K.A. Kurek, P. Berg, J. van Ophem, A. Styś, S. Jankiewicz, Beyond personal beliefs: the impact of the dominant social paradigm on energy transition choices, Energies 17 (5) (2024) 1004, https://doi.org/10.3390/en17051004.
[50] P. Ponnaganti, R. Sinha, J.R. Pillai, B. Bak-Jensen, Flexibility provisions through local energy communities: a review, Next Energy 1 (2) (2023) 100022, https://doi.org/10.1016/j.nxener.2023.100022.
[51] P. Späth, Understanding the social dynamics of energy regions—the importance of discourse analysis, Sustainability 4 (6) (2012) 1256–1273, https://doi.org/10.3390/su4061256.
[52] A.M. Minas, S. García-Freites, C. Walsh, V. Mukoro, J.M. Aberilla, A. April, et al., Advancing sustainable development goals through energy access: lessons from the global south, Renew. Sustain. Energy Rev. 199 (2024) 114457, https://doi.org/10.1016/j.rser.2024.114457.
[53] P. Ortega-Arriaga, O. Babacan, J. Nelson, A. Gambhir, Grid versus off-grid electricity access options: a review on the economic and environmental impacts, Renew. Sustain. Energy Rev. 143 (2021) 110864, https://doi.org/10.1016/j.rser.2021.110864.
[54] IEA, IRENA, UNSD, World Bank, WHO, Tracking SDG 7: The Energy Progress Report, Washington, D.C, 2023.
[55] S.C. Manchester, L.G. Swan, Off-grid mobile phone charging: an experimental study, Energy Sustain. Dev. 17 (6) (2013) 564–571, https://doi.org/10.1016/j.esd.2013.10.003.
[56] M. D'Amelio, P. Garrone, L. Piscitello, Can multinational enterprises light up developing countries? World Dev. 88 (2016) 12–32, https://doi.org/10.1016/j.worlddev.2016.06.018.
[57] A.G. Dagnachew, A.F. Hof, M.R. Roelfsema, D.P. van Vuuren, Actors and governance in the transition toward universal electricity access in sub-Saharan Africa, Energy Policy 143 (2020) 111572, https://doi.org/10.1016/j.enpol.2020.111572.
[58] International Energy Agency, Energy Access Outlook 2017: From Poverty to Prosperity, 2017.
[59] I. Bisaga, P. Parikh, To climb or not to climb? Investigating energy use behaviour among solar home system adopters through energy ladder and social practice lens, Energy Res. Soc. Sci. 44 (2018) 293–303, https://doi.org/10.1016/j.erss.2018.05.019.
[60] P.M. Murphy, S. Twaha, I.S. Murphy, Analysis of the cost of reliable electricity: a new method for analyzing grid connected solar, diesel and hybrid distributed electricity systems considering an unreliable electric grid, with examples in Uganda, Energy 66 (2014) 523–534, https://doi.org/10.1016/j.energy.2014.01.020.
[61] D. Salite, J. Kirshner, M. Cotton, L. Howe, B. Cuamba, J. Feijó, et al., Electricity access in Mozambique: a critical policy analysis of investment, service reliability and social sustainability, Energy Res. Soc. Sci. 78 (2021) 102123, https://doi.org/10.1016/j.erss.2021.102123.
[62] A. Sharma, S. Agrawal, J. Urpelainen, The adoption and use of solar mini-grids in grid-electrified Indian villages, Energy Sustain. Dev. 55 (2020) 139–150, https://doi.org/10.1016/j.esd.2020.01.005.
[63] T. Kemabonta, G. Mowry, A syncretistic approach to grid reliability and resilience: investigations from Minnesota, Energ. Strat. Rev. 38 (2021) 100726, https://doi.org/10.1016/j.esr.2021.100726.
[64] M.M. Samy, M.I. Mosaad, S. Barakat, Optimal economic study of hybrid PV-wind-fuel cell system integrated to unreliable electric utility using hybrid search optimization technique, Int. J. Hydrogen Energy 46 (20) (2021) 11217–11231, https://doi.org/10.1016/j.ijhydene.2020.07.258.
[65] P. Yadav, A.P. Heynen, D. Palit, Pay-as-you-go financing: a model for viable and widespread deployment of solar home systems in rural India, Energy Sustain. Dev. 48 (2019) 139–153, https://doi.org/10.1016/j.esd.2018.12.005.
[66] H. Harajli, F. Gordon, Willingness to pay for green power in an unreliable electricity sector: part 2. The case of the Lebanese commercial sector, Renew. Sustain. Energy Rev. 50 (2015) 1643–1649, https://doi.org/10.1016/j.rser.2015.05.053.
[67] F. Kemausuor, M.D. Sedzro, I. Osei, Decentralised energy Systems in Africa: coordination and integration of off-grid and grid power systems—review of planning tools to identify renewable energy deployment options for rural electrification in Africa, Curr Sustainable Renewable Energy Rep 5 (4) (2018) 214–223, https://doi.org/10.1007/s40518-018-0118-4.
[68] S.O. Sanni, J.Y. Oricha, Oyewole TO, F.I. Bawonda, Analysis of backup power supply for unreliable grid using hybrid solar PV/diesel/biogas system, Energy 227 (2021) 120506, https://doi.org/10.1016/j.energy.2021.120506.
[69] T. Levin, V.M. Thomas, Can developing countries leapfrog the centralized electrification paradigm? Energy Sustain. Dev. 31 (2016) 97–107, https://doi.org/10.1016/j.esd.2015.12.005.
[70] A. Kasaeian, P. Rahdan, M.A.V. Rad, W.-M. Yan, Optimal design and technical analysis of a grid-connected hybrid photovoltaic/diesel/biogas under different economic conditions: a case study, Energ. Conver. Manage. 198 (2019) 111810, https://doi.org/10.1016/j.enconman.2019.111810.
[71] D. Palit, K.R. Bandyopadhyay, Rural electricity access in South Asia: is grid extension the remedy? A critical review, Renew. Sustain. Energy Rev. 60 (2016) 1505–1515, https://doi.org/10.1016/j.rser.2016.03.034.
[72] X. Zhao, M. Ramzan, T. Sengupta, G. Deep Sharma, U. Shahzad, L. Cui, Impacts of bilateral trade on energy affordability and accessibility across Europe: does economic globalization reduce energy poverty? Energ. Buildings 262 (2022) 112023 https://doi.org/10.1016/j.enbuild.2022.112023.
[73] S. Tirado Herrero, L. Nicholls, Y. Strengers, Smart home technologies in everyday life: do they address key energy challenges in households? Curr. Opin. Environ. Sustain. 31 (2018) 65–70, https://doi.org/10.1016/j.cosust.2017.12.001.
[74] V. Mukoro, M. Sharmina, A. Gallego-Schmid, A review of business models for access to affordable and clean energy in Africa: do they deliver social, economic, and environmental value? Energy Res. Soc. Sci. 88 (2022) 102530 https://doi.org/10.1016/j.erss.2022.102530.
[75] A. Shoaib, S. Ariaratnam, A study of socioeconomic impacts of renewable energy projects in Afghanistan, Procedia Engineering 145 (2016) 995–1003, https://doi.org/10.1016/j.proeng.2016.04.129.
[76] A. Chaurey, P.R. Krithika, D. Palit, S. Rakesh, B.K. Sovacool, New partnerships and business models for facilitating energy access, Energy Policy 47 (2012) 48–55, https://doi.org/10.1016/j.enpol.2012.03.031.
[77] B.K. Sovacool, The political economy of energy poverty: a review of key challenges, Energy Sustain. Dev. 16 (3) (2012) 272–282, https://doi.org/10.1016/j.esd.2012.05.006.
[78] D. Zhang, J. Li, P. Han, A multidimensional measure of energy poverty in China and its impacts on health: an empirical study based on the China family panel studies, Energy Policy 131 (2019) 72–81, https://doi.org/10.1016/j.enpol.2019.04.037.
[79] J. Zhang, Z. Wang, Does inter-provincial energy exportation affect local energy affordability? Evidence from China, Energy Reports 8 (2022) 13848–13858, https://doi.org/10.1016/j.egyr.2022.10.299.
[80] A.L. Berka, E. Creamer, Taking stock of the local impacts of community owned renewable energy: a review and research agenda, Renew. Sustain. Energy Rev. 82 (2018) 3400–3419, https://doi.org/10.1016/j.rser.2017.10.050.
[81] A. Razmjoo, S. Mirjalili, M. Aliehyaei, P.A. Østergaard, A. Ahmadi, Nezhad M. Majidi, Development of smart energy systems for communities: technologies, policies and applications, Energy 248 (2022) 123540, https://doi.org/10.1016/j.energy.2022.123540.
[82] H. Lund, P.A. Østergaard, D. Connolly, B.V. Mathiesen, Smart energy and smart energy systems, Energy 137 (2017) 556–565, https://doi.org/10.1016/j.energy.2017.05.123.
[83] I. Dincer, C. Acar, Smart energy systems for a sustainable future, Appl. Energy 194 (2017) 225–235, https://doi.org/10.1016/j.apenergy.2016.12.058.
[84] K.T. Raimi, A.R. Carrico, Understanding and beliefs about smart energy technology, Energy Res. Soc. Sci. 12 (2016) 68–74, https://doi.org/10.1016/j.erss.2015.12.018.
[85] B.N. Stram, Key challenges to expanding renewable energy, Energy Policy 96 (2016) 728–734, https://doi.org/10.1016/j.enpol.2016.05.034.
[86] W. Strielkowski, E. Volkova, L. Pushkareva, D. Streimikiene, Innovative policies for energy efficiency and the use of renewables in households, Energies 12 (7) (2019) 1392, https://doi.org/10.3390/en12071392.
[87] B. Bonfert, 'We like sharing energy but currently there's no advantage': transformative opportunities and challenges of local energy communities in Europe, Energy Res. Soc. Sci. 107 (2024) 103351, https://doi.org/10.1016/j.erss.2023.103351.
[88] B.S. Reddy, Access to modern energy services: an economic and policy framework, Renew. Sustain. Energy Rev. 47 (2015) 198–212, https://doi.org/10.1016/j.rser.2015.03.058.
[89] A. Correljé, U. Pesch, E. Cuppen, Understanding value change in the energy transition: exploring the perspective of original institutional economics, Sci. Eng. Ethics 28 (6) (2022) 55, https://doi.org/10.1007/s11948-022-00403-3.
[90] M.B. Roberts, S.M. Adams, D. Kuch, Social license to automate batteries? Australian householder conditions for participation in virtual power plants, Energy Res. Soc. Sci. 104 (2023) 103241, https://doi.org/10.1016/j.erss.2023.103241.

[91] J. Schwartz, Energy worldviews: engaging consumers by aligning rate design strategies with personal choice, Electr. J. 31 (9) (2018) 34–37, https://doi.org/10.1016/j.tej.2018.10.009.
[92] S. Williams, M. Short, Electricity demand forecasting for decentralised energy management, Energy and Built Environment 1 (2) (2020) 178–186, https://doi.org/10.1016/j.enbenv.2020.01.001.
[93] M.C. Brisbois, Powershifts: a framework for assessing the growing impact of decentralized ownership of energy transitions on political decision-making, Energy Res. Soc. Sci. 50 (2019) 151–161, https://doi.org/10.1016/j.erss.2018.12.003.
[94] D. Brown, S. Hall, M.E. Davis, What is prosumerism for? Exploring the normative dimensions of decentralised energy transitions, Energy Res. Soc. Sci. 66 (2020) 101475, https://doi.org/10.1016/j.erss.2020.101475.
[95] A.J. Wieczorek, H. Rohracher, D. Bauknecht, K. Kubeczko, S. Bolwig, P. Valkering, et al., Citizen-led decentralised energy futures: emerging rationales of energy system organisation, Energy Res. Soc. Sci. 113 (2024) 103557, https://doi.org/10.1016/j.erss.2024.103557.
[96] D.P. Kaundinya, P. Balachandra, N.H. Ravindranath, Grid-connected versus stand-alone energy systems for decentralized power—a review of literature, Renew. Sustain. Energy Rev. 13 (8) (2009) 2041–2050, https://doi.org/10.1016/j.rser.2009.02.002.
[97] M. Tanrioven, Reliability and cost–benefits of adding alternate power sources to an independent micro-grid community, J. Power Sources 150 (2005) 136–149, https://doi.org/10.1016/j.jpowsour.2005.02.071.
[98] M.D. Leonard, E.E. Michaelides, Grid-independent residential buildings with renewable energy sources, Energy 148 (2018) 448–460, https://doi.org/10.1016/j.energy.2018.01.168.
[99] M.C. Brisbois, Decentralised energy, decentralised accountability? Lessons on how to govern decentralised electricity transitions from multi-level natural resource governance, Global Transitions 2 (2020) 16–25, https://doi.org/10.1016/j.glt.2020.01.001.
[100] B.P. Koirala, R.A. Hakvoort, E.C. van Oost, H.J. van der Windt, Community energy storage: governance and business models, in: F.P. Sioshansi (Ed.), Consumer, Prosumer, Prosumager: How Service Innovations Will Disrupt the Utility Business Model, Academic Press an imprint of Elsevier, London, San Diego CA, 2019, pp. 209–234.
[101] P. Catney, S. MacGregor, A. Dobson, S.M. Hall, S. Royston, Z. Robinson, et al., Big society, little justice? Community renewable energy and the politics of localism, Local Environ. 19 (7) (2014) 715–730, https://doi.org/10.1080/13549839.2013.792044.
[102] S. Knox, M. Hannon, F. Stewart, R. Ford, The (in)justices of smart local energy systems: a systematic review, integrated framework, and future research agenda, Energy Res. Soc. Sci. 83 (2022) 102333, https://doi.org/10.1016/j.erss.2021.102333.
[103] R. Seidl, T. von Wirth, P. Krütli, Social acceptance of distributed energy systems in Swiss, German, and Austrian energy transitions, Energy Res. Soc. Sci. 54 (2019) 117–128, https://doi.org/10.1016/j.erss.2019.04.006.
[104] R. Khalilpour, A. Vassallo, Leaving the grid: an ambition or a real choice? Energy Policy 82 (2015) 207–221, https://doi.org/10.1016/j.enpol.2015.03.005.
[105] Z. Liu, Z. Zhang, R. Zhuo, X. Wang, Optimal operation of independent regional power grid with multiple wind-solar-hydro-battery power, Appl. Energy 235 (2019) 1541–1550, https://doi.org/10.1016/j.apenergy.2018.11.072.
[106] Z. Bie, Y. Lin, G. Li, X. Jin, B. Hua, Smart grid in China: a promising solution to China's energy and environmental issues, Int. J. Environ. Stud. 70 (5) (2013) 702–718, https://doi.org/10.1080/00207233.2013.828442.
[107] International Energy Agency, Power Systems in Transition: Challenges and Opportunities Ahead for Electricity Security, 2020.
[108] Y. Nie, G. Zhang, H. Duan, An interconnected panorama of future cross-regional power grid: a complex network approach, Resources Policy 67 (2020) 101692, https://doi.org/10.1016/j.resourpol.2020.101692.
[109] T. Ahmad, D. Zhang, C. Huang, H. Zhang, N. Dai, Y. Song, et al., Artificial intelligence in sustainable energy industry: status quo, challenges and opportunities, J. Clean. Prod. 289 (2021) 125834, https://doi.org/10.1016/j.jclepro.2021.125834.
[110] G.P. Verbong, S. Beemsterboer, F. Sengers, Smart grids or smart users? Involving users in developing a low carbon electricity economy, Energy Policy 52 (2013) 117–125, https://doi.org/10.1016/j.enpol.2012.05.003.
[111] M. Broman Toft, G. Schuitema, J. Thøgersen, Responsible technology acceptance: model development and application to consumer acceptance of smart grid technology, Appl. Energy 134 (2014) 392–400, https://doi.org/10.1016/j.apenergy.2014.08.048.
[112] M.M. Rafique, S. Rehman, National energy scenario of Pakistan – current status, future alternatives, and institutional infrastructure: an overview, Renew. Sustain. Energy Rev. 69 (2017) 156–167, https://doi.org/10.1016/j.rser.2016.11.057.
[113] C. Clastres, Smart grids: another step towards competition, energy security and climate change objectives, Energy Policy 39 (9) (2011) 5399–5408, https://doi.org/10.1016/j.enpol.2011.05.024.
[114] Y. Lin, X. Tang, X. Fan, Optimization of multi-energy grid for smart stadiums based on improved mixed integer linear algorithm, Energy Rep. 8 (2022) 13417–13424, https://doi.org/10.1016/j.egyr.2022.09.070.
[115] E. Guelpa, A. Bischi, V. Verda, M. Chertkov, H. Lund, Towards future infrastructures for sustainable multi-energy systems: a review, Energy 184 (2019) 2–21, https://doi.org/10.1016/j.energy.2019.05.057.
[116] C. Wang, P. Ju, F. Wu, X. Pan, Z. Wang, A systematic review on power system resilience from the perspective of generation, network, and load, Renew. Sustain. Energy Rev. 167 (2022) 112567, https://doi.org/10.1016/j.rser.2022.112567.
[117] A. Gellert, A. Florea, U. Fiore, F. Palmieri, P. Zanetti, A study on forecasting electricity production and consumption in smart cities and factories, Int. J. Inf. Manag. 49 (2019) 546–556, https://doi.org/10.1016/j.ijinfomgt.2019.01.006.
[118] A. Steinbach, Barriers and solutions for expansion of electricity grids—the German experience, Energy Policy 63 (2013) 224–229, https://doi.org/10.1016/j.enpol.2013.08.073.
[119] G. Hoogsteen, Report on models and specification of different modii: sustainable energy system for achieving novel carbon neutral energy communities, SUSTENANCE D6.1 (2023).
[120] A. Dik, C. Kutlu, S. Omer, R. Boukhanouf, Y. Su, S. Riffat, An approach for energy management of renewable energy sources using electric vehicles and heat pumps in an integrated electricity grid system, Energ. Buildings 294 (2023) 113261, https://doi.org/10.1016/j.enbuild.2023.113261.
[121] F. Kahrl, J. Williams, D. Jianhua, H. Junfeng, Challenges to China's transition to a low carbon electricity system, Energy Policy 39 (7) (2011) 4032–4041, https://doi.org/10.1016/j.enpol.2011.01.031.
[122] A.J. Mills, G. Durepos, E. Wiebe, Encyclopedia of Case Study Research, Sage Publications, Los Angeles, 2010.
[123] J.W. Creswell, Qualitative Inquiry & Research Design: Choosing among Five Approaches, 2nd ed., Sage Publications, Thousand Oaks, 2007.
[124] M.Q. Patton, Qualitative Research and Evaluation Methods, 3rd ed., Sage Publications, Thousand Oaks Calif, 2001.
[125] S. Krupnik, A. Wagner, O. Vincent, T.J. Rudek, R. Wade, M. Mišík, et al., Beyond technology: a research agenda for social sciences and humanities research on renewable energy in Europe, Energy Res. Soc. Sci. 89 (2022) 102536, https://doi.org/10.1016/j.erss.2022.102536.
[126] D. Yanow, Interpretive analysis and comparative research, in: I. Engeli, C. R. Allison (Eds.), Comparative Policy Studies, Palgrave Macmillan UK, London, 2014, pp. 131–159.
[127] D. Hernández, L. Yoon, N. Simcock, Basing "energy justice" on clear terms: assessing key terminology in pursuit of energy justice, Environmental Justice 15 (3) (2022) 127–138, https://doi.org/10.1089/env.2021.0049.
[128] J. Schillinger, F. Helfrich, E. Aukes, L. Tummers, A. Votsis, L. Sanderink, Description of social, economic & regulatory conditions: sustainable energy system for achieving novel carbon neutral energy communities, SUSTENANCE D3.1 (2023).
[129] A. Votsis, J. Schillinger, L. Tummers, Socio-economic, governance and regulatory conditions: sustainable energy system for achieving novel carbon neutral energy communities, SUSTENANCE D3.2 (2023).
[130] Vereniging Aardehuis, Construction phase [March 26, 2024]; Available from: https://www.aardehuis.nl/index.php/en/the-story/construction-phase.
[131] Vereniging Aardehuis, The earthship concept [March 26, 2024]; Available from: https://www.aardehuis.nl/index.php/en/earthships/the-earthship-concept.
[132] Vereniging Aardehuis, Vision and Mission [March 08, 2024]; Available from: https://www.aardehuis.nl/index.php/en/earthships/vision-and-mission.
[133] Vereniging Aardehuis, Organization during construction [March 26, 2024]; Available from: https://www.aardehuis.nl/index.php/en/the-story/organization-during-construction.
[134] Vereniging Aardehuis, Preparation phase [March 26, 2024]; Available from: https://www.aardehuis.nl/index.php/en/the-story/preparation-phase.
[135] Vereniging Vriendenerf, Visie en ambitie: Een duurzaam CPO-project voor vijftigplussers, 2012.
[136] Vereniging Vriendenerf, Visie, Available from: https://www.vriendenerf.nl/Visie/.
[137] Vereniging Vriendenerf, Duurzaam wonen [November 19, 2024]; Available from: https://www.vriendenerf.nl/Duurzaam-wonen/.
[138] Vereniging Vriendenerf, Milieusparende voorzieningen, Available from: https://www.vriendenerf.nl/Milieusparende-voorzieningen/.
[139] L. Høst-Madsen, M. Purup, N. Bangsbo Dissing, The eScape project: combining archaeology and art to merge the past with the present: chapter 15, in: D. C. Comer, A. Willems (Eds.), Feasible Management of Archaeological Heritage, 2019, pp. 159–169.
[140] A.D. Lassen, A.V. Thorsen, E. Trolle, Current practices and opportunities for more sustainable public food procurement: a qualitative study among Danish municipalities and regions, Foods 12 (10) (2023), https://doi.org/10.3390/foods12101975.
[141] C.E. Scheele, J.V. Hoff, The affordances and use of green citizen engagement web tools, in: V. Kvist Johansen, S. Jensen, C. Preist, E. Eriksson (Eds.), EnviroInfo & ICT4S-Building the Knowledge Base for Environmental Action and Sustainability, University of Copenhagen, 2015, pp. 165–172.
[142] B.K. Sovacool, J. Axsen, S. Sorrell, Promoting novelty, rigor, and style in energy social science: towards codes of practice for appropriate methods and research design, Energy Res. Soc. Sci. 45 (2018) 12–42, https://doi.org/10.1016/j.erss.2018.07.007.
[143] M.Q. Patton, Qualitative Evaluation and Research Methods, 2nd ed., Sage Publications, Newbury Park Calif, 1990.
[144] L. Vila-Henninger, C. Dupuy, V. van Ingelgom, M. Caprioli, F. Teuber, D. Pennetreau, et al., Abductive coding: theory building and qualitative (re) analysis, Sociol. Methods Res. 53 (2) (2024) 968–1001, https://doi.org/10.1177/00491241211067508.
[145] F. Coenen, Y. Krozer, Description of criteria for attractive and viable citizen-centered business models: sustainable energy system for achieving novel carbon neutral energy communities, SUSTENANCE D3.4 (2023).
[146] P. Ponnaganti, J.R. Pillai, System framework and demand response schemes for different demonstrators: sustainable energy system for achieving novel carbon neutral energy communities, SUSTENANCE D2.1 (2022).

[147] A.K.S. Maisanam, A. Biswas, K.K. Sharma, Comparative analysis of hybrid renewable energy system using Homer: a case study of Silchar, India, in: T. S. Sudarshan (Ed.), Recent Advancements in Mechanical Engineering Select Proceedings of ICRAME 2021, Springer, Singapore, 2021, pp. 509–522.

[148] A.K.S. Maisanam, A. Biswas, K.K. Sharma, Integrated socio-environmental and techno-economic factors for designing and sizing of a sustainable hybrid renewable energy system, Energ. Conver. Manage. 247 (2021) 114709, https://doi.org/10.1016/j.enconman.2021.114709.

[149] H. Nie, R. Kemp, J.-H. Xu, V. Vasseur, Y. Fan, Split incentive effects on the adoption of technical and behavioral energy-saving measures in the household sector in Western Europe, Energy Policy 140 (2020) 111424, https://doi.org/10.1016/j.enpol.2020.111424.

[150] E.K. Gray, F. Fahy, R. McArdle, M. Rohse, Co-creating a community visioning methodology for energy transitions: principles, practices, and reflections, Energy Res. Soc. Sci. 118 (2024) 103783, https://doi.org/10.1016/j.erss.2024.103783.

[151] B. Nijenhuis, J. Reuling, G. Hoogsteen, J.L. Hurink, The potential of indicating energy flexibility information by EV users for application in energy management systems: a Dutch case study, in: 2023 IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids (SmartGridComm), IEEE, 2023, pp. 1–6.

[152] J.M. Weinand, M. Hoffmann, J. Göpfert, T. Terlouw, J. Schönau, P. Kuckertz, et al., Global LCOEs of decentralized off-grid renewable energy systems, Renew. Sustain. Energy Rev. 183 (2023) 113478, https://doi.org/10.1016/j.rser.2023.113478.

[153] F.A. Khan, N. Pal, S. Saeed, Review of solar photovoltaic and wind hybrid energy systems for sizing strategies optimization techniques and cost analysis methodologies, Renew. Sustain. Energy Rev. 92 (2018) 937–947, https://doi.org/10.1016/j.rser.2018.04.107.

[154] M. Katsivelakis, D. Bargiotas, A. Daskalopulu, I.P. Panapakidis, L. Tsoukalas, Techno-economic analysis of a stand-alone hybrid system: application in Donoussa Island, Greece, Energies 14 (7) (2021) 1868, https://doi.org/10.3390/en14071868.

[155] I. Batas Bjelic, R.M. Ciric, Optimal distributed generation planning at a local level – a review of Serbian renewable energy development, Renew. Sustain. Energy Rev. 39 (2014) 79–86, https://doi.org/10.1016/j.rser.2014.07.088.

[156] K. Shivarama Krishna, Kumar K. Sathish, A review on hybrid renewable energy systems, Renew. Sustain. Energy Rev. 52 (2015) 907–916, https://doi.org/10.1016/j.rser.2015.07.187.

[157] T. Moss, M. Francesch-Huidobro, Legacies of energy autarky for low carbon urban transitions, in: A. Luque-Ayala, S. Marvin, H. Bulkeley (Eds.), Rethinking Urban Transitions: Politics in the Low Carbon City, Routledge Taylor & Francis Group, Abingdon Oxon, New York, 2018.

[158] F. Alkemade, B. de Bruin, A. El-Feiaz, F. Pasimeni, L. Niamir, R. Wade, Social tipping dynamics in the energy system, Earth Syst. Dynam. 15 (2) (2024) 485–500, https://doi.org/10.5194/esd-15-485-2024.

[159] H. Winkler, A.F. Simões, E.L. La Rovere, M. Alam, A. Rahman, S. Mwakasonda, Access and affordability of electricity in developing countries, World Dev. 39 (6) (2011) 1037–1050, https://doi.org/10.1016/j.worlddev.2010.02.021.

[160] M. Karatayev, S. Hall, Y. Kalyuzhnova, M.L. Clarke, Renewable energy technology uptake in Kazakhstan: policy drivers and barriers in a transitional economy, Renew. Sustain. Energy Rev. 66 (2016) 120–136, https://doi.org/10.1016/j.rser.2016.07.057.

[161] S. Pachauri, Reaching an international consensus on defining modern energy access, Curr. Opin. Environ. Sustain. 3 (4) (2011) 235–240, https://doi.org/10.1016/j.cosust.2011.07.005.

[162] N. Möllers, K. Zachmann (Eds.), Past and Present Energy Societies: How Energy Connects Politics, Technologies and Cultures, transcript Verlag, Bielefeld, Germany, 2012.

[163] C. Renfrew, The Emergence of Civilisation: The Cyclades and the Aegean in the Third Millennium BC, Oxbow Books, Oxford and Philadelphia, 2011.