Project no.: **101022587**

Project full title: **Sustainable energy system for achieving novel carbon neutral energy communities**

Project Acronym: **SUSTENANCE**

Deliverable number:	**D3.1**
Deliverable title:	**Description of social, economic & regulatory conditions**
Work package:	WP3
Due date of deliverable:	M12
Actual submission date:	M19 - 31/01/2023
Start date of project:	01/07/2021
Duration:	42 months
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Dissemination level of this deliverable	**PU**
Nature of deliverable	R

This project has received funding from 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 under the SUSTENANCE project. Any results of this project reflect only this consortium'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.

Document history

Version no.	Date	Authors	Changes
1.0	14-10-2022	Schillinger et al.	Full draft including data for demo sites in Denmark, Netherlands and Poland
2.0	27-10-2022	Schillinger et al.	Revisions based on internal review; report includes demo sites in Denmark, Netherlands and Poland
3.0	31-01-2023	Schillinger et al.	Revisions to include demo sites in India

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Executive Summary

This report provides an overview of socio-economic, governance and regulatory obstacles that might hinder the development and operation of autarkic local integrated energy systems. Energy autarky here is defined as a situation in which a local community is able to use its own energy resources and infrastructure to cover its energy needs, rather than having to rely on the infrastructure of the larger energy grid and energy imports from elsewhere. While energy autarky as such is theoretically not linked to sustainable or low-carbon energy systems, local autarky aspirations commonly relate to the expansion of local renewable energy production. Additionally, the factors to achieve sustainable, autarkic energy systems are in line with the European Union's strategy on local energy transitions towards renewable energy sources and local energy communities.

The SUSTENANCE project '*SUSTainable ENergy system for Achieving Novel Carbon neutral Energy communities*' explores new approaches to establish such energy systems, based on seven demo sites across four countries: Denmark (one site), India (three sites), Netherlands (two sites), and Poland (one site). This report contributes to the SUSTENANCE project by analysing the different demo sites and identifying the obstacles to transitions towards more autarkic local energy systems.

This analysis is based on the notion of local energy transitions as socio-technical system change, and guided by a two-dimensional typology that combines physical-technical and socio-regulatory characteristics of the different sites (Figure 1.1). This typology for autarkic energy communities was developed as part of work package 3 within the SUSTENANCE project.

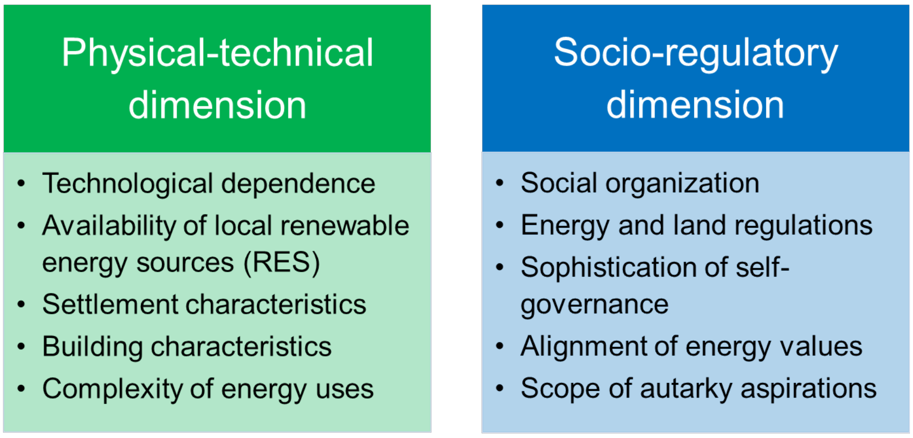

Figure 1.1. Energy system characteristics analyzed within the SUSTENANCE typology for autarkic energy communities.

Based on the demo site characteristics across the four participating countries, the demo sites can be categorised into three groups:

First, European residential sites, which focus on existing, electrified neighbourhoods switching to more renewable energy sources and a higher degree of self-sufficiency. These sites are generally limited by the status of the local energy infrastructure, as the local production of renewable energy and the sharing of energy within the community via a micro grid was not a consideration during the development of the neighbourhood or, in the case of off-grid and micro grid applications, was not permissible under then-regulations. A key strength of these demo sites are existing governance structures and social organisation platforms linked to village and neighbourhood associations, which provide a strong social foundation for the development of more autarkic energy systems.

Second, Indian residential sites, which focus on existing villages of varying degrees of electrification, with the goal to improve electrification by building on renewable energy sources and autarky principles. These sites are generally limited by the availability of local renewable energy sources – especially wind speeds are not particularly abundant, and by the limited formal representation of users of the energy systems in governance structures – they are hardly socially organized and thus in a weak position to influence decision-making. Key strengths of the Indian sites are the ample space available to develop new infrastructures, and the strong alignment of energy values and motives in the community to develop autarkic energy systems.

Third, electric mobility sites, which focus on self-sufficient electric vehicle charging systems powered by local energy production from renewable sources. As these sites were specifically designed to be as self-sufficient as possible, their energy infrastructure is designed to accommodate the challenges of renewable energy production, such as storage facilities and management systems focused on balancing energy flows within the system. Their comparatively small scale additionally means that energy regulations may not apply. In order to provide a larger contribution to local energy transitions and encourage active participation of energy users, these sites need to support local community-building for example by expanding social activities and outreach.

The complexity of local energy uses is a key determinant of how challenging the development towards a higher degree of energy autarky will be. While most demo sites – and particularly the Indian residential demo sites – have relatively simple energy use profiles, the Polish case of the Własnościowa Spółdzielnia Mieszkaniowa housing cooperative in Sopot stands out as the most complex case, combining domestic and commercial uses as well as lighting of public spaces and the operation of shared spaces within the buildings. This has a high potential for balancing energy flows within the neighbourhood, but will require a more careful management of the available energy resources and might increase the need for local energy storage.

Finally, the analysis of the different demo sites revealed a split regarding the primary motivation of project communities to develop their local energy system towards a higher degree of renewable energy production and autarky. Among the seven SUSTENANCE demo sites are projects that are primarily motivated by economic motives (i.e., lowering energy costs) and projects primarily motivated by environmental motives (i.e., reducing carbon emissions in the energy sector). However, within each project community, energy values and motivations are generally aligned, which is conducive to the development of a more autarkic, renewable energy system. At the same time, any differences that exist in primary motivations needs to be considered when designing interventions within SUSTENANCE, to ensure acceptance by the different project communities.

1 Introduction

1.1 Autarkic systems and the local energy transition

This report provides an overview of socio-economic, governance and regulatory obstacles that may hinder the development and operation of autarkic local integrated energy systems. In this context, we apply the definition by Müller et al. (2011, p. 5802) who define energy autarky as *"[…] a situation in which a region does not import substantial amounts of energy resources from other regions, but rather relies on its own resources to satisfy its need for energy services."* Energy autarky thus closely overlaps with the notion of energy self-sufficiency, and the two terms are often used interchangeably.

Scenarios for the energy autarky of various communities have been assessed as a key component of local energy transitions in different European countries (e.g., Hauber & Ruppert-Winkel, 2012; Homan et al., 2019; Pieńkowski & Zbaraszewski, 2019; Schmidt et al., 2012; Späth, 2012). While energy autarky as such is theoretically not linked to sustainable or low-carbon energy systems, local autarky aspirations are commonly linked to the expansion of local renewable energy production. Müller et al. (2011) emphasize that the achievement of sustainable, autarkic energy systems depends on three closely related factors: 1) the use of local renewable energy resources in place of energy imports; 2) the decentralization of the energy system; and 3) the increase in energy efficiency of both energy supply and demand. These factors are in line with the European Union's strategy on local energy transitions, including the European Green Deal (European Commission [EC], 2019) and the EU Strategy for Energy System Integration (European Commission [EC], 2020), as well as the EU's revised Renewable Energy Directive (2018/2001) and Internal Electricity Market Directive (2019/944) on the establishment of local energy communities.

Figure 2.1 provides a simplified overview of a local energy system based on renewable energy sources (RES), whereby the development towards a high degree of energy autarky corresponds with the reduction of energy imports from external energy production via the larger grid. Instead, local resources are used to cover energy needs in an integrated system that includes electricity, heat and fuel for a variety of uses.

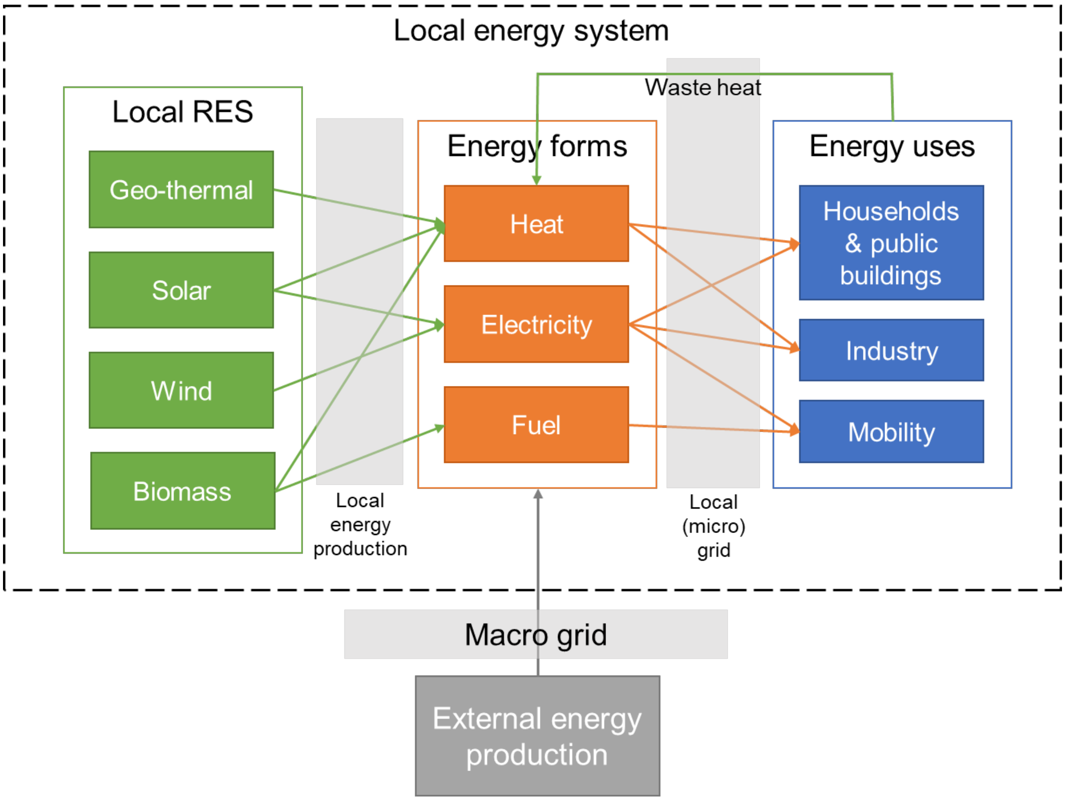

Figure 2.1. Simplified diagram of a local energy system, which includes local energy production from renewable energy sources (RES) and energy imports from external energy production. When developing towards energy autarky, the local system increases the local production and decreases energy imports from external production. Simplified based on Müller et al. (2011).

1.2 SUSTENANCE project

The SUSTENANCE project explores new approaches to establish local, sustainable and integrated energy systems that can support the transition towards carbon-neutral energy communities. The project develops and demonstrates new technological solutions, organisational configurations and business models to maximize the local use of renewable energy sources and to enable the sharing of energy between individual households or shared infrastructures within the local community. It particularly focuses on local self-sufficiency and integrated multi-carrier micro-grid systems that serve a variety of local energy uses and users.

Demonstration activities in the SUSTENANCE project are conducted at several demo sites across four countries: Denmark (one site), India (three sites), Netherlands (two sites), and Poland (one site). In each demo site, a range of technical and social interventions are designed and implemented to support the transition towards a self-sufficient, citizen-centred local energy system based on renewable energy sources.

The SUSTENANCE project team comprises academic institutions as well as public and private sector actors from all four countries.

1.3 Report objectives

This report is part of SUSTENANCE Work Package 3 (WP3), which addresses social factors related to the decarbonisation of local integrated energy systems and develops organisational configurations and business models that support the development of more autarkic energy communities. As the first work package deliverable, the main objective of this report is to *identify and analyze the socio-economic, governance and regulatory obstacles that hinder the development and operation of autarkic local integrated energy systems in the SUSTENANCE demo sites*.

Within SUSTENANCE WP3, a typology for autarkic energy communities was developed, reflecting the socio-technical characteristics of local energy communities that can be conducive to the development of more autarkic energy systems. This typology guided data collection from the different demo sites and forms the analytical framework in this report. We first apply the framework for an efficient assessment of the current conditions in each site and the identification of possible autarky pathways. We then use it to identify the strengths and weaknesses in each demo site based on information provided by local key actors and SUSTENANCE project partners, and create an energy autarky signature that provides a baseline for further analysis across the SUSTENANCE project. Based on these insights, we finally identify and analyze different obstacles to the development of an autarkic energy community in each demo site. Figure 2.2 provides an overview of this analytical process.

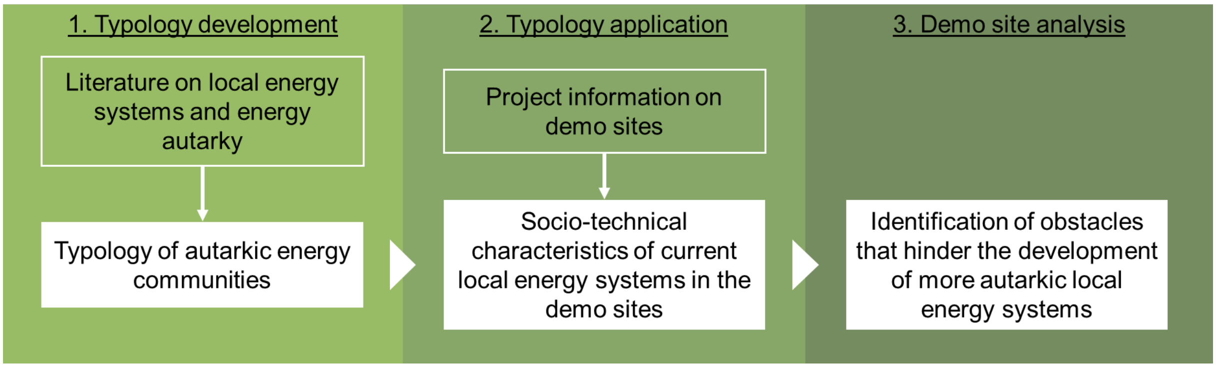

Figure 2.2. Analytical process to identify obstacles to the development of more autarkic local energy systems in the SUSTENANCE demo sites.

2 Socio-technical systems and system change

This section briefly outlines the conceptual background of the present analysis and introduces the notion of the energy transition as socio-technical system change. It explains why this conceptualisation matters for the SUSTENANCE project, and how it is incorporated in our analysis of obstacles for the development of autarkic energy systems.

2.1 Energy systems as socio-technical systems

We apply a *systems approach* to the local energy transition towards higher self-sufficiency or autarky. Systems approaches are useful for the analysis of complex issues, as they provide a tool to identify and evaluate different factors and processes that affect overall system performance or specific dynamics (Holling, 2001). A system is a set of interconnected components that function together to fulfill a certain purpose, such as energy supply. Each of these components plays a vital role within the system, is influenced by other processes in the system and, although each component has its own properties, cannot be seen in isolation from the rest of the system (Ackoff, 1994; Meadows, 2008).

The energy system is a *socio-technical system*, i.e., a system that includes both technical components, such as different pieces of energy infrastructure or equipment, and social components, such as the different energy users or the legislative and regulatory frameworks that govern the energy sector (van de Graaf & Sovacool, 2020). In such a system, technical and social processes influence each other, and have to be analysed in tandem rather than separately. Socio-technical systems therefore ask for an integration of 'hard' and 'soft' systems approaches, i.e., for an analysis that goes beyond well-defined technological problems that have one optimal solution (a certain type of technology), and looks at the interplay of different processes within the system that influence each other. It might not be possible to ultimately define or quantify a specific problem, instead, people's different perspectives on the system, its components and its main purpose play a role. An optimal technical solution in one system might not work in another, due to a difference in social dynamics (Reynolds & Holwell, 2010). In the energy system, the suitability of different technical solutions can, for instance, be influenced by various usage patterns or market coordination mechanisms (Rassa et al., 2019).

Approaching the question of energy autarky in the context of the socio-technical energy system benefits our analysis in several ways.

First, it allows us to identify a range of *non-technical barriers to autarky* and the expansion of renewable energy production that are related to social, economic, or regulatory obstacles. Such possible barriers include, for instance, existing regulatory frameworks that are tailored to centralised energy production from fossil fuels (Butenko, 2016), the wider public discourse around energy systems and attachment to fossil fuels (Sovacool, 2009), and technological acceptability challenges on both the individual and the societal level (Hess & Coley, 2014; Seidl et al., 2019). By considering the socio-technical energy system as a whole, technological advancement can thus be accompanied by interventions that address social barriers and advance 'societal readiness' (Yun & Lee, 2015).

Second, it provides a useful framework to understand existing *participatory energy systems*, and to design new ones where none exist. Participatory processes are key to the European Union's energy transition strategy, in which local energy communities take a central position. These energy communities are intended to facilitate collective energy activities on the local level, including the exchange of energy and democratic decision-making on energy issues within the community (European Commission [EC], n.d.). The in-depth engagement with social dynamics can provide new insights on spaces for participation within the energy system and a wide variety of participatory practices that go beyond conventional public engagement in energy policy-making (Chilvers et al., 2018). New opportunities for participation in the energy system play a particularly important role in the context of grass-root innovation and bottom-up system change based on local social movements (see also Seyfang & Smith, 2007; Szejnwald Brown & Vergragt, 2012).

Third, it helps to identify important social system components that are needed in *knowledge transfer projects* with the aim to implement technology in new contexts. By approaching the energy system as a socio-technical system, we inherently acknowledge that energy technology cannot simply be transplanted into a different setting and expected to work just as well. Instead, socio-economic and cultural dynamics of the target area need to be considered when choosing suitable technical solutions, to ensure feasibility and social acceptance and to create opportunities for active participation (Ortiz et al., 2012). This is of particular importance for the SUSTENANCE project, which aims to implement innovations to increase energy self-sufficiency in the vastly differing contexts of Denmark, the Netherlands, Poland and India.

Consequently, when we analyse the local energy systems in the SUSTENANCE demo sites, we need to consider both technical and social aspects in each community, as well as their linkages and interactions.

2.2 Energy transitions as socio-technical system change

Building on the notion of the energy system as a socio-technical system, we can approach energy transitions as system changes in which technical and social components *co-evolve*. Technological innovation alone cannot invoke an energy transition; instead, it needs to be accompanied with corresponding business models, user practices and, in some cases, new institutions and regulations (Li et al., 2015; Schot & Geels, 2008; Verbong & Geels, 2012). Local energy transitions as we imagine them in the SUSTENANCE project, i.e., towards a higher level of self-sufficiency based on local renewable energy sources, will also require new forms of active citizenship and cooperation between citizens (Devine-Wright, 2007).

The required co-evolution of technical and social components makes large-scale energy transitions relatively slow processes. Geels (2002) pioneered the notion of a multi-level perspective on socio-technical transitions as a way of understanding incremental system change that eventually leads to larger transitions (Figure 3.1). In this multi-level setting, change starts within localised 'niches' that allow for small-scale experimentation with new technologies or social innovations. The different demo sites in SUSTENANCE can be considered as such niches. Successful experimentation in one niche may catch on and be replicated elsewhere, eventually leading to a shift in established practices, rules and technology, also referred to as the 'socio-technical regime.' In the energy sector, such regimes include, for instance, prevailing energy market mechanisms and regulations or national energy sector strategies. Over time, as regimes change, the overall (energy) landscape will begin to develop in a new direction. In the case of SUSTENANCE and the energy transition envisioned by the EU, this would be a transition towards renewable energy sources and local, self-sufficient energy communities across the Member States, among others.

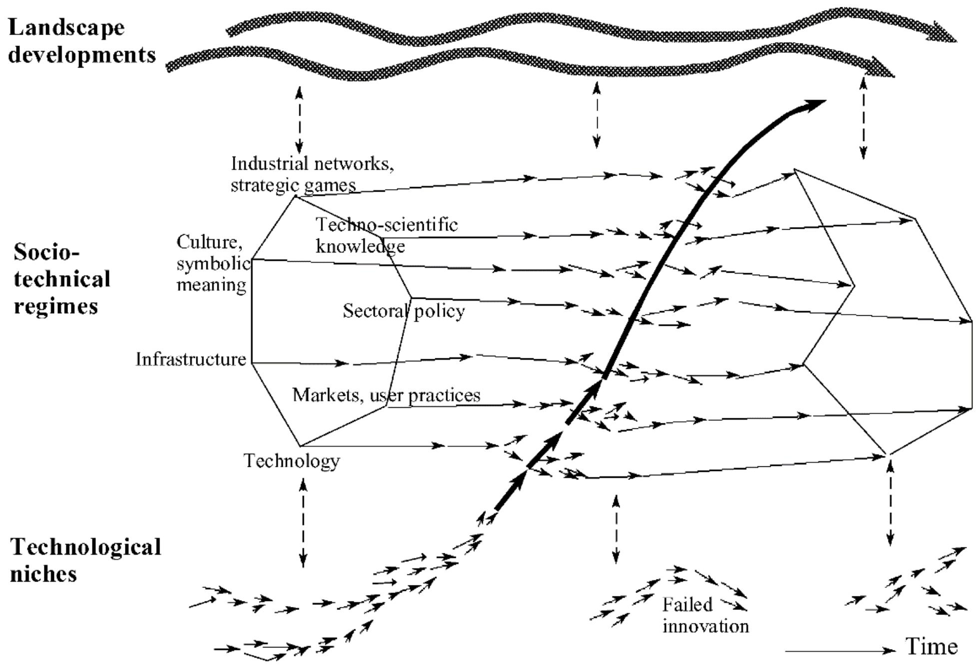

Figure 3.1. A dynamic multi-level perspective on socio-technical transition. Source: Geels (2002).

2.3 Obstacles to system change

The objective of this report is to identify obstacles to the transition of local energy systems in the SUSTENANCE demo sites towards a higher degree of autarky. Obstacles can, for instance, reduce the effectiveness or diffusion of a new technology within an energy community, or limit the opportunities for new actors to get involved in the system transition.

In this analysis, we differentiate between two types of obstacles: 1) *challenges*, which are obstacles within the local energy system that can reasonably be addressed and overcome by interventions within the energy system (the 'niche') over the course of the SUSTENANCE project, and 2) *limitations*, which are obstacles related to the larger energy regime or landscape and cannot be directly influenced from within the local energy system in a way that would lead to their resolution during the SUSTENANCE project, such as energy regulations. In these cases, the system and the planned interventions need to adapt to the limitations.

The analytical framework for the analysis of potential obstacles in the different SUSTENANCE demo sites, a typology of autarkic energy communities, will be introduced in Section 4 below.

3 Typology of autarkic energy communities

As outlined in the previous section, energy systems comprise a range of technical and social components, all of which play a role in local energy transitions. Within SUSTENANCE, we developed a typology of key components that are relevant for the development of more autarkic local energy systems, which provides an analytical framework for the assessment of the different SUSTENANCE demo sites.

This typology of autarkic energy communities comprises a technological dimension and a social dimension, each of which consists of different system characteristics that are related to the development of autarkic energy systems (Table 4.1). The characteristics were identified based on scientific literature related to energy autarky, renewable energy sources and local energy communities.

Table 4.1. Overview of the characteristics within the SUSTENANCE typology of autarkic energy communities.

Characteristic	Description	Ideal state for transition towards autarky
Physical-technical dimension		
Technological dependence	Grid integration, i.e., the degree to which the community is dependent on its integration into the larger grid for energy supply and storage	Local energy infrastructure that allows local community to share and store energy within the system, without depending on the larger grid for these services
Availability of local renewable energy sources (RES)	Mix of local sources of renewable energy (e.g., wind, solar, geothermal) and the total capacity to provide local renewable energy	Local energy demand can be fully covered with local RES
Settlement characteristics	Built environment and land use patterns surrounding the community, including room for further development and opportunities for energy-related synergies	Area provides sufficient space for the further development of energy infrastructure and the use of nature-based solutions to increase energy efficiency
Building characteristics	Architectural and engineering characteristics of individual structures (e.g., insulation), and the related energy demands	Passive or zero-energy building standards that minimize the need to supply the building with external energy
Complexity of energy uses	Range of energy uses within the community that need to be covered by the local system, including linkages to other sectors (e.g., food, mobility, waste)	High degree of synergies between the different energy uses, and a high degree of flexibility to react to high or low energy supply if needed
Social-regulatory dimension		
Social organisation	Diversity, density and complexity of social networks (e.g., clubs and organisations) within the community	Active and organised community in which residents commonly come together over shared interests and have formed strong social networks
Energy and land regulations	Legislative and regulatory context for the development of an autarkic energy system, related to both technical and social innovations	High degree of freedom to experiment and implement local solutions independently
Sophistication of self-governance	Type, structure, and “weight” of governance system in place, including the level of autonomy awarded to the community and the ability to govern its energy affairs	High level of local community autonomy and structures for effective self-governance

Alignment of energy values	Motivations for local energy transitions (incl. autarky) within the community, and the degree of agreement among community members on these values	High degree of agreement / alignment of values related to autarkic energy system within the community
Scope of autarky aspirations	Long-term aspirations of the community with regards to autarky in the energy sector and/or other sectors	Aspirations that are in line with the technical and social conditions of the community, while also pushing further development towards zero-carbon local energy systems

3.1 Characteristics in the physical-technical dimension

In the physical-technical dimension, the typology covers characteristics that directly relate to physical infrastructure as well as (renewable) energy supply and demand, giving an overview of the technical potential for an autarkic energy system.

Technological dependence addresses the degree to which the local energy system depends on the larger energy grid to function, related to both the transmission and the storage of energy. In order to minimize this dependence and support an autarkic system, local energy systems should include their own micro-grid through which community members can share energy with each other, and local energy storage, e.g., batteries (Müller et al., 2011).

The *availability of local renewable energy sources* determines whether local energy demand can be met from the renewable energy sources available to the system. This includes the capacity of currently installed renewable energy generation, e.g., photovoltaic panels or heat pumps, as well as the potential to increase the renewable energy generation if needed (Trutnevyte et al., 2012; Woch et al., 2014).

Settlement characteristics and *building characteristics* assess the built environment of the community itself and the surrounding areas, providing insights on the potential for more efficient energy use and the corresponding decrease in energy demand, as well as opportunities for future community development (Bossi et al., 2020; Givoni, 1998; Lwasa et al., 2022).

The *complexity of energy uses* captures the range of users and associated uses that need to be covered by the local energy system. It takes note of possible synergies between uses in the energy system and other, related systems, e.g., mobility, waste and food, and of the flexibility of different uses, e.g., the use of large household appliances or EV charging stations during times of high energy generation (Weinand et al., 2022).

3.2 Characteristics in the socio-regulatory dimension

In the socio-regulatory dimension, the typology covers characteristics that relate to the local energy community and to the socio-economic and regulatory context in which it is developed. This dimension reflects the need for social interaction and organisation within the community to support the development towards a more autarkic energy system, as well as the emphasis on citizen-centered and community-based energy systems within SUSTENANCE.

Social organisation within this dimension refers to the networks and social structures within the community, including, but not limited to those related to energy, that provide insights into the relationships between members of the community and the social capital available to support the local energy transition (Bouw et al., 2022; Dóci & Vasileiadou, 2015).

Energy and land regulations determine the regulatory framework in which the transition towards a higher degree of autarky takes place, for instance related to energy market regulations and the legality of sharing energy directly within the community rather than via the larger grid (D'Alpaos & Andreolli, 2021; Mengelkamp et al., 2018).

The *sophistication of self-governance* covers the type, structure and 'weight' of the governance system within the energy community, including decision-making processes and associated sets of rules. It gives insight on the ability of the local community to govern its local energy affairs and on its relationships with other energy governance stakeholders outside of the local system (Creamer et al., 2018; Hoppe et al., 2015).

The *alignment of energy values* within the community assesses whether community members are in agreement on the motivations behind the local energy transition, including the transition towards a higher degree of autarky. A high alignment of values and motivations is conducive to effective cooperation on energy issues within the community (Ecker et al., 2017; Wirth et al., 2018).

Lastly, the *scope of autarky aspirations* reflects the overall plan related to energy autarky within the community, and, similar to energy values, whether community members are in agreement. Depending on the envisioned scope of autarky, more elaborate socio-technical changes might be needed in the future, for instance if the community is also pursuing self-sufficiency in sectors like food or water management (Ecker et al., 2017; Späth, 2012).

3.3 Typology application

This deliverable applies the typology to the different SUSTENANCE demo sites in order to map the current status of the local energy system and to identify possible obstacles for the development of a more autarkic energy system. Table 4.2 provides an overview of the guiding questions related to each characteristic that were used to operationalise the typology in the analysis. The current status of each demo site is visualised in an 'autarky signature' (Figure 4.1) that shows the strengths and weaknesses in each energy system, related to the transition towards a more autarkic system. It should be noted that while we are assessing the status and potential of the different demo sites along the ten characteristics of the typology to structure the analysis, the characteristics are closely related and might influence each other. For instance, the development of energy infrastructure (technological dependence) or residential building standards (building characteristics) are influenced by the applicable regulations in each demo site (energy and land regulations). We take note of these linkages in our analysis, but they might not be immediately visible from the autarky signatures.

A full description of the typology, including more elaborate discussions of each characteristic and the use of the typology across SUSTENANCE WP3 is provided in project deliverable D3.3.

Table 4.2. Guiding questions for the analysis of each typology characteristic in the SUSTENANCE demo sites.

Characteristic	**Guiding questions for analysis**
Physical-technical dimension	
Technological dependence	• How is the project site integrated into larger energy grids? • Is there a micro-grid within the project site? • Is there energy storage capacity?
Availability of local renewable energy sources (RES)	• What is the current installed capacity for energy production from RES, compared to the energy demand? • Are expansions planned? • In the absence of any specific plans, what is the technical potential for different RES in the area?
Settlement characteristics	• Where is the project site located, and what are land use patterns in its surroundings? • How high is the building density in the project area? • Is space available for the development of additional (energy) infrastructure if needed? • Are climate architecture or nature-based solutions applied in the area?
Building characteristics	• What types of buildings are included in the project? (e.g., detached houses, row houses) • What kinds of environmental or energy standards were applied in the design and construction of the buildings? • How well are buildings insulated? • How are basic services delivered to the buildings?
Complexity of energy uses	• What are the main energy uses in the project site? • Is there flexibility in when most energy is used? • Are there synergies with other sectors, such as mobility or solid waste, that can be explored to reduce energy demand?
Social-regulatory dimension	
Social organisation	• What kinds of associations or clubs exist within the project community? • Are there any associations or clubs specifically on energy or sustainability topics? • How much do community members interact with each other in general, and are there specific platforms for it?
Energy and land regulations	• Which regulations apply to energy systems in the project area? • How difficult are they to comply with? • Is it permissible to exchange energy directly within the community, for instance by use of a micro-grid?
Sophistication of self-governance	• Is there a formal citizens’ representation within the community, and are community members able to influence decision-making? • Are there specific rules in place that guide interactions and energy management within the community? • Does the community collaborate with other, external actors on energy issues?
Alignment of energy values	• What motivates community members in the project site to switch to local, renewable energy and become as self-sufficient as possible? • Do community members agree on what the most important motivations / energy values are?
Scope of autarky aspirations	• Does the project community strive for full energy independence? • Does the project community strive for self-sufficiency or independence in other sectors than energy as well, e.g., food or water?

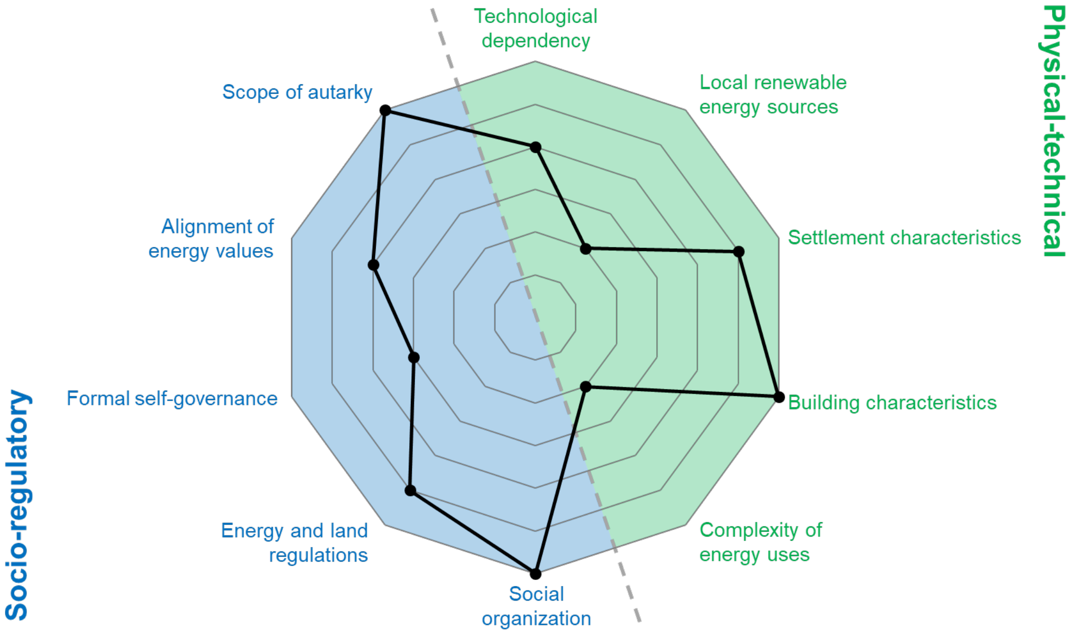

Figure 4.1. Example of an autarky signature, based on the SUSTENANCE typology of autarkic energy communities. Created by authors.

4 SUSTENANCE demo sites

The following sub-sections provide analyses of the different SUSTENANCE demo sites. For each site, we first outline the current conditions of the local energy system and the community that surrounds it. We structure this analysis along the previously introduced autarky typology, allowing us to develop a comprehensive overview of the setting in which further development towards autarky will take place. We then analyse the current conditions and autarky signature of each demo site to identify the key obstacles that could hinder this development.

4.1 Denmark

4.1.1 Voerladegård

Voerladegård is a village of ca. 550 inhabitants in the municipality of Skanderborg in the Central Denmark (Midtjylland) Region. The demo site includes 20 existing houses within Voerladegård and the neighbouring small village Dørup, which will be retrofitted with new technology to make use of local renewable energy sources. A new integrated community energy system with active citizen participation is envisioned to provide opportunities for energy sharing between households.

Key stakeholders in this demo case as identified by project partners are the local prosumers (with heat pumps, phase change material-based thermal storage tanks, solar-PVs and electric vehicles), the local aggregator (Neogrid), and the distribution system operator (AURA). Neogrid will take the central position in the envisioned use case for SUSTENANCE, which includes establishing contacts to other commercial players.

4.1.1.1 Physical-technical characteristics

Technological dependence

The houses included in the demo site are individually connected to the larger municipal energy grid, whereby some houses are consumers only, while others have a reciprocal connection to the grid and provide surplus electricity from their local PV installation to the grid. The local distribution system operator and electricity supplier to the demo site is the company N1.

There is no micro grid within the community, and a grid specifically connecting the 20 demo houses would be difficult to construct, as they are spread out across Voerladegård and Dørup.

Local renewable energy resources

Of the 20 houses included in the Voerladegård demo site, nine houses already have solar PV installations for electricity generation, and one house is equipped with a solar collector for hot water. Across Voerladegård and Dørup, there are photovoltaic systems with an estimated capacity of 50 kW, with an additional 50 kW planned in the foreseeable future.

Energy for heating currently originates from individual natural gas boilers, however, houses will switch to individual heat pumps as part of the SUSTENANCE project.

Settlement characteristics

Voerladegård and Dørup are rural villages at the edge of the municipality of Skanderborg. The villages are surrounded by agricultural lands to the south, and a forest and a big lake to the north. The area is sparsely built, with approximately 2.9% and 1% of the administrative area of Voerladegård and Dørup constituting built-up areas, respectively (Figure 5.1).

Buildings in the villages are predominantly residential, comprising detached and semi-detached houses.

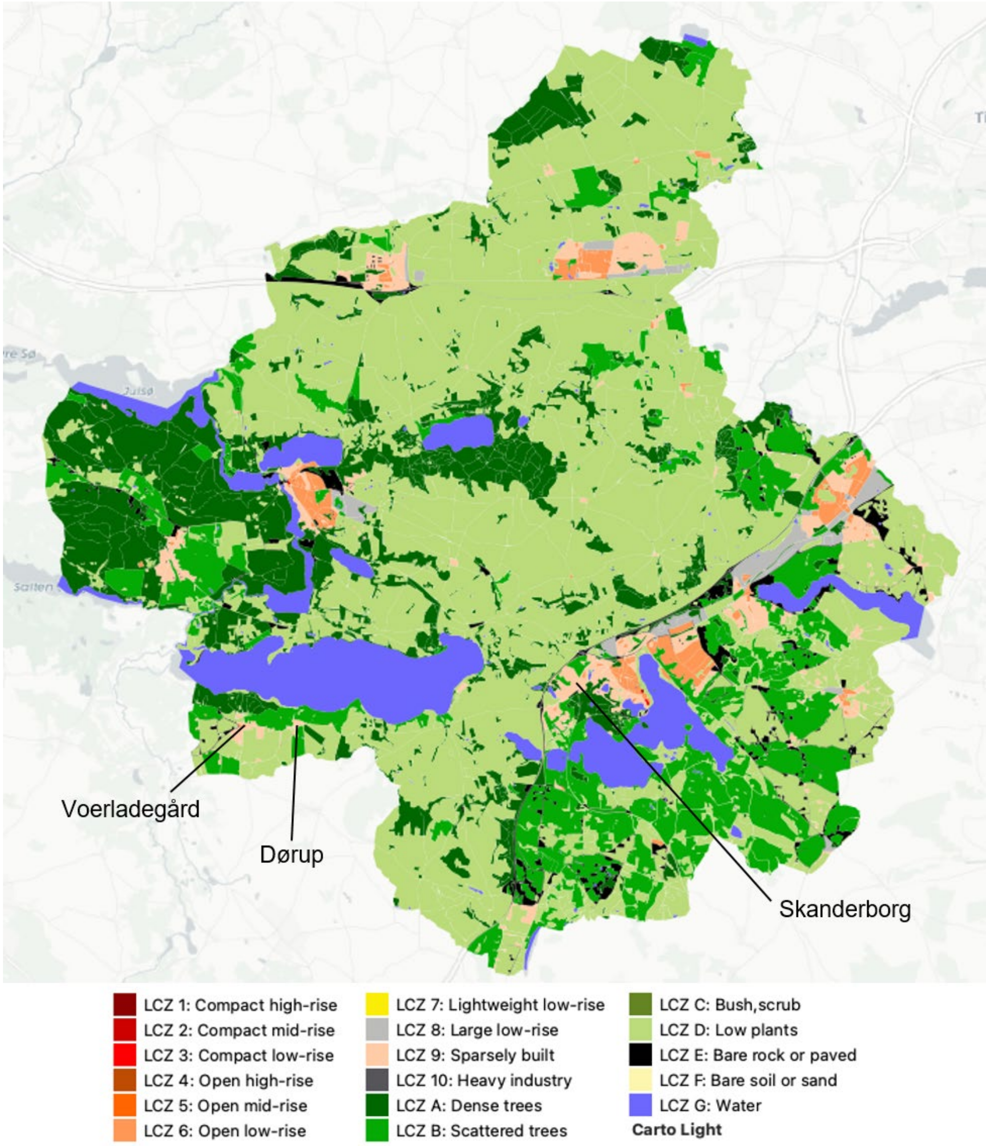

Figure 5.1 Local Climate Zone (LCZ) map of Skanderborg municipality, indicating built-environmental configurations surrounding the Voerladegård demo site. Produced with the Geoclimate algorithms of Lab-STICC (CNRS UMR 6285 - DECIDE team - GIS group) based on primary data by OpenStreetMap.

Building characteristics

The 20 houses in the demo site are detached and semi-detached brick houses. They receive electricity from the local grid and are connected to the municipal water and sewage network for water and wastewater services. The project buildings are insulated using rockwool, in accordance with the Danish insulation standards and building regulations during the respective building period, starting in the 1960s.

Natural gas boilers in each house provide heating, with the heating consumption estimated to range between 72 and 150 kWh/m² per year among the 20 buildings.

Energy uses

The Voerladegård demo site includes residential houses only, making heating and domestic electricity consumption the primary energy uses. In addition, eight of the 20 houses in the demo site reportedly have EV charging stations.

The SUSTENANCE project will explore opportunities for synergies between different energy sources and uses, particularly between the electricity-consuming heat pumps and EV chargers and the electricity-producing PV systems, by applying battery and smart management of the energy consumption.

4.1.1.2 Social-regulatory characteristics

Social organisation

Voerladegård is a socially active community with a range of different clubs and associations, although there does not seem to be any clubs with a specific focus on energy or sustainability yet. Nevertheless, this provides social platforms and networks to upscale SUSTENANCE innovations for a larger citizen-centered energy community.

The local residents' association (Voerladegård Borgerforening) acts as a platform for local communication and citizens' initiatives, and includes a number of organisations that focus on key aspects of daily life in Voerladegård, such as the Voerladegaard Community House Organisation and the local sports club (Voerladegård IF).

Regulations

The project interventions in Voerladegård need to abide by a number of regulations related to heat supply, building standards and noise limits, all of which are easy to comply with according to the project team.

The main regulatory challenge for Voerladegård is related to the Danish transposition of the EU directives on energy communities, which in its current form dictate that the exchange of energy from one neighbour to another must go via the larger grid and pay the applicable local and national charges. This makes it less attractive to share energy between neighbours or within the community. However, these additional charges need to be seen in comparison to the current increase in electricity prices, which might make the local production and sharing of electricity from renewable sources, i.e., PV installations, economically more favourable after all.

Formal governance

The local residents' association Voerladegård Borgerforening functions as a forum for the village residents. Community members can participate in the annual general assembly and be elected as board members. The association's statutes and annual reports, as well as assembly and board meeting minutes are available via the village website (www.voerladegaard.dk). Voerladegård Borgerforening is also represented in Skanderborg's village community (Landsbyfællesskabet), which cooperates with the municipality on issues related to rural development.

Within SUSTENANCE, the key actors involved with project implementation in the demo site are Skanderborg Municipality, which is involved in project planning, the company Neogrid, which will take the central position in the envisioned use case for SUSTENANCE by managing the smart energy system, and Voerladegård Borgerforening, which plays an important role for the communication with citizens and their acceptance of the project. Energy provider Aura Energi and Aalborg University are involved in the project to simulate the local grid system for analysing and mitigating possible congestions.

The municipality is the local authority for heat systems, including, but not limited to district heating. However, the heating system in the case of the SUSTENANCE demo site is so small that it does not require a permit from the municipality.

Overall, the relationship between the different key organisations is good, and citizens are reported to mostly trust these organisations. Overarching rules, e.g., on the relationship between the municipality and the local residents' association via Skanderborg's village community, shape the interactions between actors.

Values and motivations

The primary motivation for the people in Voerladegård to switch to RES-based energy supply and pursue local self-sufficiency is economic. New energy solutions need to be cheaper than the current system, which has been intensified by the sharp increase in energy prices since early 2022. Other motives, mostly related to environmental concerns and the political or social statement of becoming independent from fossil fuel imports since the onset of the Ukraine war, are also common within the community. However, community members reportedly agree on economic motives being the main driver of the local energy transition in this demo site. Accordingly, interventions will have to be more cost-effective than current energy solutions in order to be broadly accepted.

Scope of autarky aspirations

The main focus of the project community is on the economic benefits of being a renewable energy community, with little emphasis on self-sufficiency as such. It is therefore unlikely that the community would want to pursue autarky in other sectors or go beyond the level of self-sufficiency that is cost-effective in the energy sector.

4.1.1.3 Energy autarky signature

Voerladegård is an active community that is just starting to take a stronger interest in energy topics and improving their local energy infrastructure, motivated by changes in the Danish energy regulations and the recent significant increase in energy prices. The energy autarky signature for the village (Figure 5.2) reflects its strong social organisation and governance structures, which can provide an important platform to further energy discussions within the community.

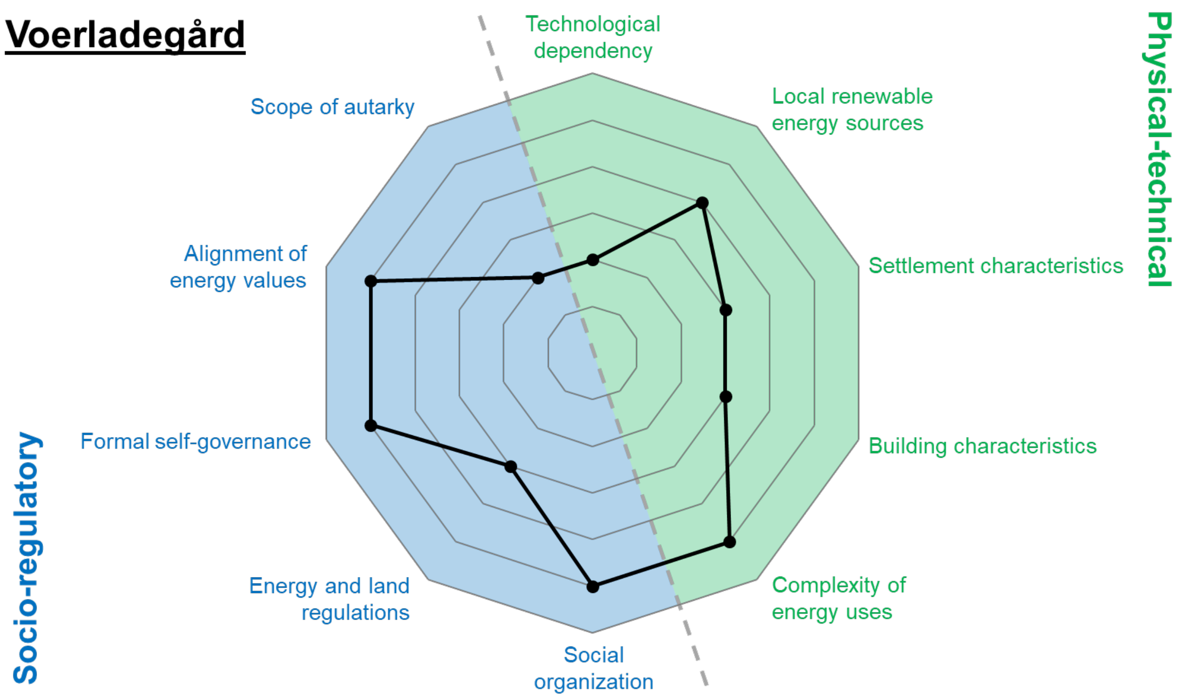

Figure 5.2 Energy autarky signature for Voerladegård, following the SUSTENANCE typology of autarkic energy communities. Created by authors.

4.1.1.4 Key obstacles for the development of an autarkic local energy community

Based on the current autarky aspirations, the current energy infrastructure alongside other elements of the *physical-technical dimensio*n is the key *challenge* in making Voerladegård a more autarkic, renewable energy community. This includes the production of energy from RES as well as an increase in efficiency and smart demand management, all of which are being addressed in the SUSTENANCE project.

In order to support further development towards energy autarky, ways need to be found to make higher levels of self-sufficiency economically attractive, which is *limited* by the current *energy regulations* that affect the cost-effectiveness of sharing energy within the community. Alternatively, a push for stronger dialogues on environmental issues could push the community towards prioritising ecological benefits over the current economic motivations. This *re-alignment of energy values* would certainly be a *challenge* and dependent not just on social organisation and community coherence, but also on the socio-economic resources of residents, which will determine whether they are able to pay extra for more renewable, autarkic energy.

4.2 India

4.2.1 Barubeda village

Barubeda is a remote agricultural village in Jharkand state with around 50 households. The village is not connected to any larger energy grid, and only has limited access to water. Inhabitants primarily use firewood for cooking, and kerosene-based lamps for lighting. There is no access to public transportation services, and the nearest road is located 3 km away from the village. For several months each year, the men of the village migrate to the closest city for work.

The goal within SUSTENANCE is to develop an off-grid integrated energy system based on local renewable energy sources. Specific utilities provided in the new local energy system include electricity, a domestic water supply system, a transportation system based on e-rickshaws, biogas- and biomass-based cooking, and a multi-utility-based heating, cooling and drying facility. Planned energy sources include solar PV systems, wind and biogas, supported by a new battery system for energy storage.

4.2.1.1 Physical-technical characteristics

Technological dependence

As stated, Barubeda is a remote off-grid village. There is currently no connection to a larger grid, creating high potential for Barubeda to develop an autarkic energy system. To improve the living standards of the villagers, the goal is to connect the circa 50 households to a partial network. This is a micro-grid or subnet for internal distribution, which in turn is connected to the larger grid. The type of grid integration implemented here is a collective connection with autonomous internal distribution mechanisms, whereby locally produced energy is being fed to the grid. Specifically, the goal is to ensure 24/7 power, through a connection to the larger grid and by installing wind and solar energy as well as a battery system.

Local renewable energy resources

Currently there is no installed capacity for any local energy source in Barubeda. For SUSTENANCE, the plan is to install wind turbines and solar panels for local energy production. Specifically, there will be seven wind turbines that produce 1 kW electricity each and a photovoltaic system to produce 30 kW in total. It must be stated that, while there is high photovoltaic power potential in Jharkhand State, wind speeds are quite low in this area.[1] Therefore, the SUSTENANCE project team will develop and test a prototype for innovative low-speed wind turbines. Nevertheless, it remains unclear if local energy demand can be fully covered with local renewable energy production, despite the relatively basic energy uses of the community (see section on energy uses).

Settlement characteristics

Barubeda is a rural village in Jharkhand state, around 90 kilometres south-east of the city of Jamshedpur. The village is surrounded by agricultural lands, which in turn are surrounded by forests. The village is situated between two rivers: the Subamarekha river on the east and the Kharkai river on the west. The village is made up of mostly residential buildings, which are detached or semi-detached houses. Besides that, there are several public and commercial buildings. The building density is average compared in the region. The land used in the SUSTENANCE project is approximately 7 hectares. This provides sufficient space for further development of energy infrastructure. This is key, since the houses are expected not to be fit for rooftop installations (see next section).

[1] *Photovoltaic power potential and wind speeds were retrieved from Global Wind Atlas and Global Solar Atlas.*

Building characteristics

The circa 50 houses in Barubeda are, as stated, either detached or semi-detached. Most of these are so-called Kutcha houses, a type of house commonly seen in rural areas. This type has walls made up of bamboo, mud, grass, reed, stones, thatch, straw, leaves and unburnt bricks – i.e. materials that can be found easily in forests or other natural environments. Hence, they are not fixed structures like apartments or buildings. Some of the houses have roofs that contain asbestos. There are currently no systems in place to supply water and electricity, nor to treat wastewater. Neither are there insulation materials or systems for heating in place. In sum, there are no environmental or energy standards in place for the design or construction of the houses to minimize the need for external energy. However, this does not seem necessary in the first place considering the warm climate in the state of Jharkhand.

Energy uses

The Barubeda village consists mostly of residential houses. Therefore, primary energy use is for domestic load. Although, compared to the other demo sites in SUSTENANCE, this includes very basic energy use in households and no heating. Additionally, energy will be used for the water supply system and for charging e-rickshaws; there will be two charging stations in the demo site. The energy will be supplied by the wind and solar installations, combined with a battery. Besides this, biogas will be provided for cooking applications.

The SUSTENANCE project will explore several opportunities for synergies to reduce energy demand. First, between energy and mobility, as e-rickshaws will be introduced as subsidized transportation options for the villagers, which will be charged on-site with the surplus of locally produced electricity.
Second, between energy and water, as water supply systems will be installed in selected households, which run on locally produced energy. Third, between energy and cooking, since biogas will be introduced to replace firewood for cooking applications.

4.2.1.2 Social-regulatory characteristics

Social organisation

There is not much information available about the social organization of the project community in Barubeda. It is unclear to what extent there is an active and organized community in which residents come together, or whether there is much interaction between residents. What is known, is that there are no clubs or associations within the project community; neither on energy or sustainability topics, nor on unrelated topics. Simultaneously, there does seem to be a high degree of consensus regarding the energy system to be installed in Barubeda (see section on values and motivations), which does hint at some degree of social organization.

Regulations

The project interventions in the Barubeda village have to comply to various regulations at the State and Central Government level. According to the project team, these are moderately difficult to comply with.

Formal governance

Similar to the social organization of the community, the governance network does not include many actors or organizations. Besides the SUSTENANCE project team, there is the Barubeda Gram Panchayat, which is a public organization. This organization cooperates with the SUSTENANCE team wherever this is required, for example for administrative approvals. There is no formal residents' representation within the community, though in interaction with the SUSTENANCE team, the residents do seem to be able to influence decision-making. There is no set of overarching rules and norms (formal or informal) that shapes how the residents, the project team and Barubeda Gram Panchayat interact with each other. Yet, there is very strong trust throughout the community in the project team to implement the local energy system.

Values and motivations

There are three common motivations across the Barubeda community for establishing a local, renewable energy system and becoming self-sufficient. The first and most important motive is economic: the residents of Barubeda are economically poor and therefore appreciate measures for cost saving. Simultaneously, ecological and social motives also play a role to some extent. There is a common aim or interest across residents to reduce carbon emissions and to take charge of their own energy system. Overall, there does not seem to be any disagreement in the community, implying that these motives are generally not disputed.

Scope of autarky aspirations

The main focus of the project community in Barubeda is to provide 24/7 access to energy and to do so in a cost-efficient manner. Since the village is remote and currently off-grid, and its residents are relatively poor, an energy system with micro-grid and locally produced energy is simply the most desirable option. Hence, autarky and self-sufficiency are not objectives as such but are aspirations in line with the technical and social conditions within the Barubeda community.

4.2.1.3 Energy autarky signature

Barubeda is a community that seeks to improve the villagers' living conditions by getting connected to the grid. The interests of the community lie with energy access, rather than with sustainability of energy. Considering the relatively poor residents of the village, the autarky aspirations are mostly economic and focused on cost efficiency. The energy autarky signature for Barubeda (Figure 5.3) shows weaknesses in terms of local renewable energy sources, self-governance and social organization, as well as strengths in terms of technological dependency and actual space to implement new infrastructures.

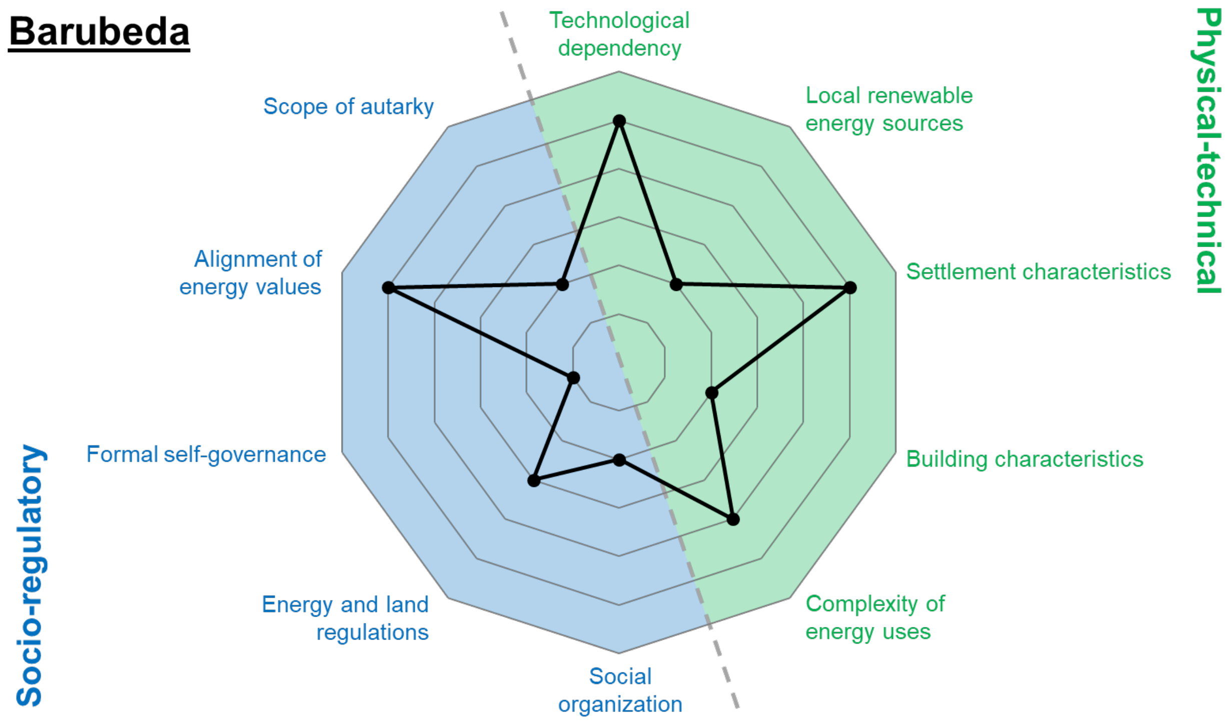

Figure 5.3 Energy autarky signature for Barubeda, following the SUSTENANCE typology of autarkic energy communities. Created by authors.

4.2.1.4 Key obstacles for the development of an autarkic local energy community

The energy autarky signature is quite limited, however, this is related to the fact that there is currently no energy system in place in the first place. Simultaneously, this implies that there is high potential for developing an autarkic energy system; there is no dependence on a larger energy grid or complexity of energy uses, while there is sufficient space for additional infrastructures and a high degree of consensus in the community. Yet there remain several obstacles that need to be addressed. The voice and position of the residents needs to be further organized and established. This is necessary to create more social organization in the community and to establish a more sophisticated network for self-governance; this is to ensure that the needs of the energy users themselves are effectively taken into account. There are also some limitations that cannot (easily) be addressed and might stand in the way of full autarky. These are the energy and land regulations that are decided upon at the national level and therefore difficult to influence, and the limited availability of wind as local renewable energy source.

4.2.2 Borakhai village

Borakhai is a village in Assam state in eastern India, located close to the city of Silchar. The village is partially electrified, but electricity is only available for a limited number of hours each day. Domestic water supply is unreliable. Inhabitants primarily use firewood for cooking and kerosene-based lamps for lighting, although some houses have a liquefied petroleum gas (LPG) connection. The transportation system is very limited and unreliable.

The demo site in Borakhai village comprises around 80 houses, split across two locations that are close to each other. Within SUSTENANCE, a multi-energy cluster based on renewable energy sources will be developed for the village, which will include electricity and domestic water supply systems, an e-rickshaw-based transportation system, and a biowaste-to-manure conversion facility. Power generation will be based on solar PV systems and wind, coupled to a battery storage system.

4.2.2.1 Physical-technical characteristics

Technological dependence

Compared to Barubeda village, Borakhai village is in a relatively comfortable situation, since it is partly and temporarily electrified; it has a weak and unreliable grid connection. To further improve the living standards of the villagers, the goal is to connect all of the circa 80 households to a more reliable partial grid. This is a micro-grid or subnet for internal distribution, which in turn is connected to the larger grid. The type of grid integration is similar to Barubeda village and is a collective connection with autonomous internal distribution mechanisms, whereby locally produced energy will be fed into the grid. Here too, the goal is to ensure 24/7 power supplied by a larger grid and to install solar and wind energy sources combined with a battery system.

Local renewable energy resources

As stated, Borakhai village is currently partly and temporarily electrified. This implies that some houses have a connected load of less than 200 W, limited to a few hours a day. For others it is a maximum power of 0.5 kW. Overall, the villagers are getting electricity for one third of the day. For SUSTENANCE, the plan is to install wind turbines and solar panels for local energy production. Specifically, there will be four wind turbines that produce 1 kW electricity each and a photovoltaic system to produce 30 kW in total. It must be stated that the photovoltaic power potential in Assam state is moderate and wind speeds are quite low in the area.[2] Though the plan is to develop a hybrid solar PV and wind system to increase the use of renewables. It is yet unclear if local energy demand can be fully covered with local renewable energy production, despite the low complexity of energy use (see section on energy uses).

Settlement characteristics

Borakhai is a rural village in the Assam state, around 10 kilometres south of the city of Silchar and located west of the Barak River. The village is surrounded by built environment and agricultural lands. The village is made up of mostly residential buildings, which are detached or semi-detached houses. Besides that, there are several public and commercial buildings. The building density is average compared in the region. Land used in the SUSTENANCE project is approximately 7 hectares. This provides sufficient space for further development of energy infrastructure. This is key, since not all houses are expected to be fit for rooftop installations (see next section).

Building characteristics

The circa 80 houses in Borakhai are, as mentioned, either detached or semi-detached. Most of these are so-called Kutcha houses, a type of house commonly seen in rural areas. This type has walls made up of wood and unburnt bricks – i.e. materials that can be found easily in forests or other natural

[2] Photovoltaic power potential and wind speeds were retrieved from Global Wind Atlas and Global Solar Atlas.

environments in the area. Hence, they are not fixed structures like apartments or buildings. Some of the houses have roofs that contain asbestos. There are currently no systems in place to supply water and electricity, nor to treat wastewater. Neither are there insulation materials or heating systems in place. In sum, there are no environmental or energy standards in place for the design or construction of the houses to minimize the need for external energy. However, this does not seem necessary in the first place considering the warm climate in the state of Assam.

Energy uses

The Borakhai village consists of mostly residential houses. Therefore, primary energy uses are for domestic load. Similar to Barubeda, this includes very basic energy use in households and no heating. Additionally, energy will be used for the water supply system and for charging e-rickshaws; there will also be two charging stations in the demo site. The energy will be supplied by the wind and solar installations, combined with a storage system. Besides this, biogas will be provided for cooking applications.

The SUSTENANCE project will explore several opportunities for synergies. First and foremost between energy and mobility, as e-rickshaws will be introduced as subsidized transportation options for the villages, which will be charged on-site with the surplus of locally produced energy. Second, between energy and solid waste as it ill be converted to manure. Third, between energy and water, as water supply systems will be in installed in selected households, which run on locally produced energy.

4.2.2.2 Social-regulatory characteristics

Social organisation

There is not much information available about the social organization of the project community in Borakhai. To what extent the residents interact with each other and are organized in the community is unclear. What is known, is that a Village Energy Committee (VEC) has been constituted. This committee is expected to play a key role in the execution of the project in terms of supporting and facilitating the field installations, commissioning activities, collecting energy/utility usage charges from the residents, and helping in the long-term establishment of the local energy system.

Regulations

Similar to Barubeda village, the project interventions in Borakhai have to comply to various regulation and the State and Central Government level. According to the project team, these are moderately difficult to comply with.

Formal governance

The governance network in the project community of Borakhai is mainly influenced by two organizations. First, the Borakhai Gaon Panchayat, a public organization. The project team collaborates closely with this organization wherever this is required, for example for administrative approvals. Second, there is the Assam Power Distribution Company Ltd (APDCL), also a public organization. This organization provides the necessary support for grid integration. The residents of Borakhai are formally represented in the VEC (see section on social organization), which indicates that they are able to influence decision-making to some extent. Simultaneously, there is no set of overarching rules and norms (formal or informal) that shapes how the project team, Borakhai Gaon Panchayat and the VEC interact with each other. Yet, there is very strong trust throughout the community and in the project team for the implementation of the project.

Values and motivations

There are three common motivations across the Borakhai community for establishing a local, renewable energy system and becoming self-sufficient. The first and most important motive is economic: the residents of Borakhai are economically poor and hence appreciate measures for cost saving. Simultaneously, ecological and social motives also play a role to some extent. There is a common aim or interest across residents to reduce carbon emissions and to take charge of their own energy system. Overall, there does not seem to be any disagreement in the community, implying that these motives are generally not disputed.

Scope of autarky aspirations

The main focus of the project community is to expand the existing energy system to make it more reliable and ensure 24/7 access to energy, and to do so in a cost-efficient manner. Since the village is remote and its residents are relatively poor, an energy system with micro-grid and locally produced energy is simply the most desirable option. Hence, autarky and self-sufficiency are not objectives as such but are aspirations that are in line with the technical and social conditions within the Borakhai community.

4.2.2.3 Energy autarky signature

Borakhai is a community that seeks to improve the currently limited supply of energy, by expanding the existing energy system. The interest of the community lie with reliability, rather than sustainability of the energy system. Similar to Barubeda, the autarky aspirations are mostly economic and focused on cost efficiency, considering the socio-economic conditions in the village. The energy autarky signature for Borakhai (Figure 5.4) shows weaknesses in terms of local renewable energy sources and self-governance, as well as strengths in terms of social organization and low complexity of energy uses.

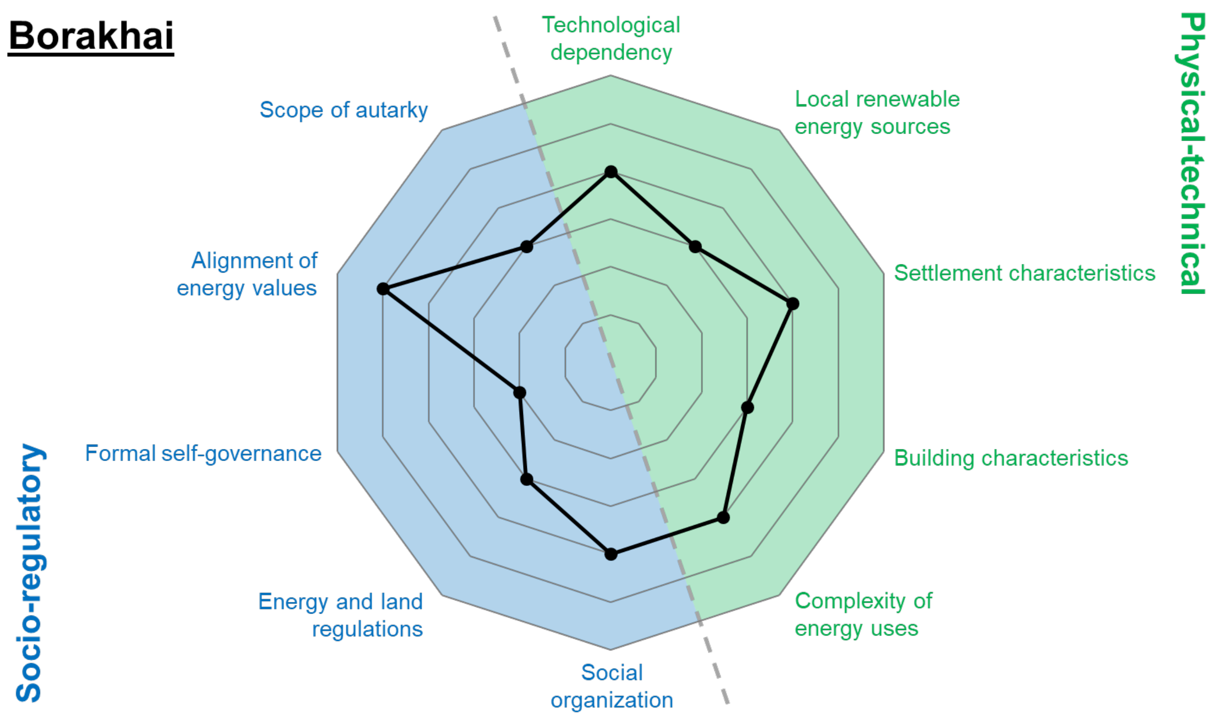

Figure 5.4 Energy autarky signature for Borakhai, following the SUSTENANCE typology of autarkic energy communities. Created by authors.

4.2.2.4 Key obstacles for the development of an autarkic local energy community

The energy autarky signature for Borakhai is somewhat limited, however, this is strongly related to the fact that there is a limited energy system in place at this point. This simultaneously implies that there is quite some potential for further developing an autarkic energy system; there is ample space for additional infrastructures and a high degree of consensus across residents, while there is low dependence on the existing electricity grid and no complexity of energy uses. Yet there remain some key obstacles to be addressed. While residents are formally represented in the VEC, public organizations are more strongly represented indicating that the level of autonomy of the community is limited. A more prominent set of overarching rules may provide opportunities in this regard. Moreover, there are two limitations that cannot (easily) be addressed and might stand in the way of full autarky. Similar to Barubeda, these are the energy and land regulations that are decided upon at the national level and therefore difficult to influence, and the somewhat limited potential of both solar and wind energy sources.

4.2.3 IIT Bombay campus

The IIT Bombay campus is located within the urban area of Mumbai, the second most-populous city of India with a population of 12.5 million. The campus itself houses more than 10,000 people and receives 24/7 electricity from the main grid. It also has a solar PV system of ca. 1 MW installed capacity. The objective of the demo site is to set up a smart integrated energy system comprising a smart electric building with its own micro-grid and EV charging infrastructure, including vehicle-to-grid (V2G) services.

4.2.3.1 Physical-technical characteristics

Technological dependence

The IIT Bombay campus in Mumbai provides a significantly different demo site, compared to the two rural villages of Barubeda and Borakhai in India. The IIT campus already has a connection to the grid, via a partial network. This results in 24/7 power supply from the main grid. Moreover, the campus already has a rooftop solar PV system of around 1 MW installed capacity. The plan for IIT Bombay is to expand the energy system with an intelligent electric vehicle charging infrastructure, utilizing local renewables, which will be coupled with a smart electric building system.

Local renewable energy resources

As mentioned, the IIT Bombay campus already has a rooftop solar PV installation that makes up for 1 MW. This installed capacity for solar energy will not be expanded. However, the plan is to add a wind turbine for 3 kW electricity. Although, while photovoltaic power potential in Mumbai is quite high, wind speeds are relatively low in the area.[3] It is thus still a question if local energy demand can be fully covered with local renewable energy production.

Settlement characteristics

The IIT Bombay campus is located in the urban region of Mumbai, the sixth most populated metropolitan area in the world. It comprises of detached or semi-detached houses. The project demonstration site is surrounded by public buildings, residential buildings and commercial buildings. The land used in the project area is around 500 hectares and the density is high. Space for further development of infrastructures is limited, but buildings appear to be fit for installations on rooftops.

Building characteristics

The IIT Bombay campus comprises of mostly detached or semi-detached buildings. These are concrete buildings with sufficient water supply and a wastewater treatment system in place. Electricity supply is adequate coming from the main grid. There is a sufficient ventilation system in place. There are no insulation materials used and there is no heat supply systems installed. In sum, there are no environmental or energy standards in place for the design or construction of the buildings to minimize the need for external energy. However, this does not seem necessary in the first place considering the warm climate in the city of Mumbai.

Energy uses

Whereas energy use in the Barubeda and Borakhai is mostly for domestic load, this is different for the IIT Bombay campus. Energy use is mostly for providing educational services, and hosting students and employees. Besides this, energy use is for the more than 10 charging points that will be installed at the IIT Bombay campus.

Therewith, the SUSTENANCE project will mostly explore synergies between energy and mobility. The project focuses on expanding the existing energy system with an intelligent electric vehicle charging infrastructure.

[3] Photovoltaic power potential and wind speeds were retrieved from Global Wind Atlas and Global Solar Atlas.

4.2.3.2 Social-regulatory characteristics

Social organisation

There is not much information available about the social organization of the project community at the IIT Bombay campus. It is unclear to what extent there is an active and organized community in which residents come together, or whether there is much interaction between users of the building and energy system. What is known, is that there are no clubs or associations within the project community; neither on energy or sustainability topics, nor on unrelated topics. Simultaneously, there appears to be a high degree of consensus regarding the energy system to be installed (see section on values and motivations), which does hint at some degree of social organization.

Regulations

The project interventions at IIT Bombay campus have to comply to various regulation and the State and Central Government level. According to the project team, these are moderately difficult to comply with.

Formal governance

As with the social organization of the community, the governance network does not include many actors or organizations. Besides the SUSTENANCE project team, there is the IIT Bombay campus administration, which is a public organization. The two IIT Bombay campus administration cooperates with the SUSTENANCE team wherever this is required, for example for administrative approvals. There is no formal representation of the users of the building or energy system. Moreover, there is no set of overarching (formal or informal) rules to shape the interaction between the SUSTENANCE project team, the IIT Bombay campus administration and the users. Simultaneously, there appears to be very strong trust throughout the community in the project team to implement the local energy system.

Values and motivations

It is unclear whether there are common values or motivations in the community at IIT Bombay campus for expanding its local, renewable energy system and becoming self-sufficient. Though there does not seem to be any disagreement in the community, implying that whatever the motives are, these are generally not disputed.

Scope of autarky aspirations

The main focus of the project community at IIT Bombay campus is to develop an intelligent electric vehicle charging infrastructure, utilizing local renewables, which will be coupled with a smart electric building system. Autarky and self-sufficiency are not objectives as such, though the related aspirations fit with the technical and social conditions at the IIT Bombay campus.

4.2.3.3 Energy autarky signature

The IIT Bombay campus seeks to expand the existing energy system with an intelligent electric vehicle charging infrastructure, utilizing local renewables, which will be coupled with a smart electric building system. The interest of the community lies with achieving synergies with mobility. The energy autarky signature for the campus shows weaknesses in terms of technological dependency and settlement characteristics, but also strengths in terms of local renewable energy sources and building characteristics.

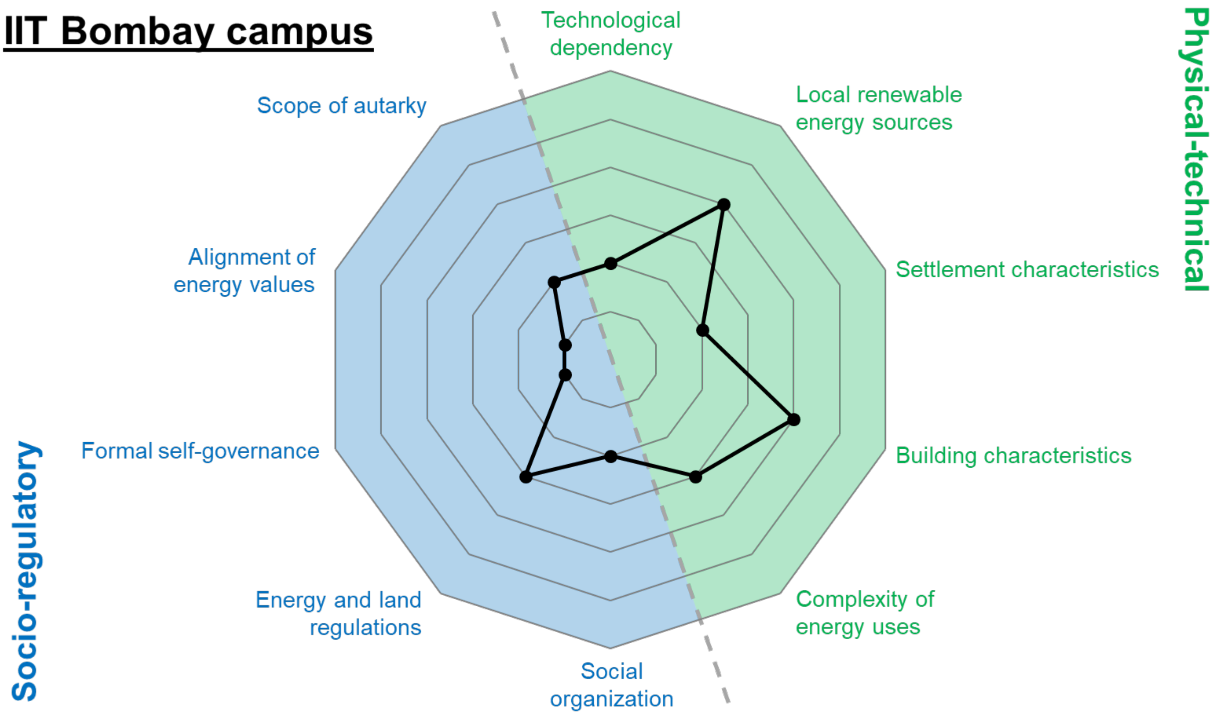

Figure 5.5. Energy autarky signature for IIT Bombay campus, following the SUSTENANCE typology of autarkic energy communities. Created by authors.

4.2.3.4 Key obstacles for the development of an autarkic local energy community

The energy autarky signature for the IIT Bombay campus is rather limited, but there is certainly potential to further develop the autarkic energy system: a photovoltaic energy system is already in place and energy uses are relatively simple, which makes it quite easy to expand the energy system to comply with energy use. A challenge that should be addressed relates to the role of users of the buildings and the energy system. Information on this is limited: it is unclear if they are to some extent organized in the governance structure of the University itself. Still, it appears that users could benefit from a more established and independent form of representation in the governance network. This would create more influence on decision-making, a key feature of autarkic energy communities. There are also a few limitations that cannot (easily) be addressed, most notably the limited space for further development of infrastructures due to the high density in the area. In addition, the fact that the project has to comply with energy and land regulations at the national level, seems to limit the freedom to experiment and implement local solutions independently.

4.3 Netherlands

4.3.1 Vriendenerf

Vriendenerf is a community-led eco-housing project in the village of Olst in Overijssel. It comprises 12 residential units and a community building, all built between 2016 and 2017. The houses were constructed according to ‘zero energy building’ standards and are equipped with solar panels, heat pumps and ground thermal storage. The community recently also constructed an EV charging station. Within SUSTENANCE, Vriendenerf aims to explore ways to exchange energy and flexibility within the community, with the underlying objective to increase the community's sustainability and achieve a higher level of renewable energy generation.

4.3.1.1 Physical-technical characteristics

Technological dependence

The Vriendenerf community is integrated into the larger municipal electricity grid via a reciprocal, i.e., two-way, connection, meaning it receives electricity from outside of the community, while also providing locally produced electricity back to the grid. Each residential unit is connected to the electricity grid via its own meter and feeds the surplus electricity from its solar panels back to the grid individually. Residential units are not connected to the gas grid, only the common building currently receives gas for heating purposes (see 'Local renewable energy resources'). The houses in the Vriendenerf community are served by three different energy suppliers that supply 'green' energy: Greenchoice (9 residential units plus common building), VandeBron (2 residential units), Pure Energie (1 residential unit).

Vriendenerf does not have its own micro-grid or local battery capacity, meaning it is dependent on the municipal grid for the facilitation of all energy transactions and the storage of surplus energy.

Local renewable energy resources

The local electricity demand is met with solar PV systems on each building. Each row of three residential units has 69 PV panels installed, distributed over the three units as 24 – 21 – 24 panels, with a total installed capacity of 6,360 – 5,565 – 6,360 Wp, respectively (Table 5.1). After covering the local in-unit electricity demand, an estimated surplus of 2,000-3,000 kWh is provided to the grid per residential unit each year.

Residential units have individual ground source heat pumps to cover their energy demands with regards to heating, passive cooling and domestic hot water. The electricity needed to operate these heat pumps is provided by the solar PV system. The common building, however, is still connected to the gas grid and uses a high-efficiency boiler for heating and warm water. The community is planning to replace this boiler with an electric ground source heat pump in the foreseeable future to eliminate the need for gas.

The surplus energy production from RES within the Vriendenerf community shows that the required resources are locally available. It should also be noted that the building characteristics contribute to a low energy demand (see 'Building characteristics'), which simplifies the full coverage of energy demand from local RES.

Table 5.1. Estimated annual electricity production and use of Vriendenerf buildings. Source: Vriendenerf website (https://www.vriendenerf.nl/).

	End-of-row unit	Middle-of-row unit
Electricity production PV panels	6400 kWh/yr	5600 kWh/yr
Electricity use for heating, cooling, ventilation, warm water	3500 kWh/yr	3500 kWh/yr

Electricity available for other domestic uses	2900 kWh/yr	2600 kWh/yr

Settlement characteristics

The Vriendenerf eco-housing project is a suburban neighbourhood on the southern edge of Olst. It is surrounded by low-density residential uses to the north, and agricultural areas to the south (Figure 5.3).

The project covers 0.56 ha, including four clusters of three row houses each, a common building and a number of small sheds (Figure 5.4). The buildings are surrounded by green spaces, a small pond and fruit and vegetable gardens, which provides additional space for new small-scale energy infrastructure if needed (Figure 5.5).

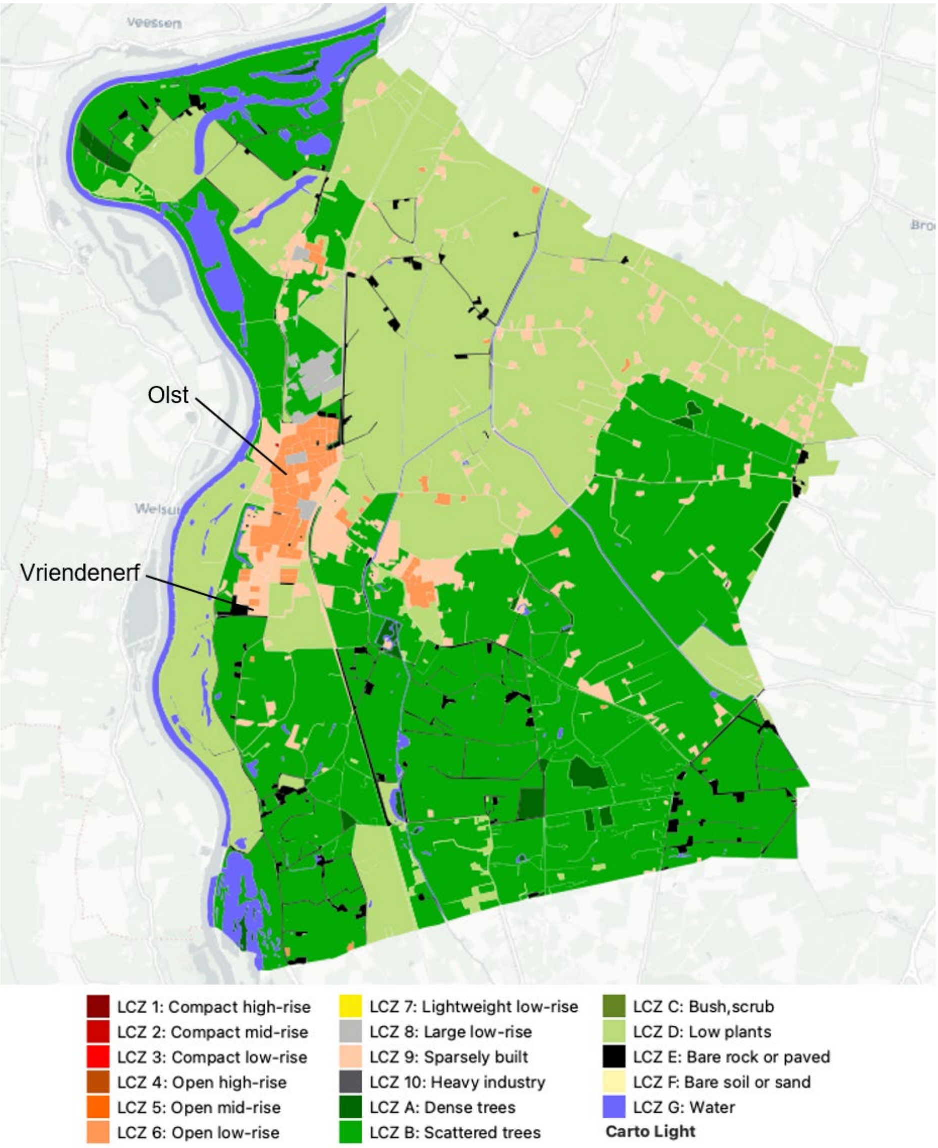

Figure 5.6. Local Climate Zone (LCZ) map of Olst-Wijhe municipality, indicating built-environmental configurations surrounding the Vriendenerf demo site. Produced with the Geoclimate algorithms of Lab-STICC (CNRS UMR 6285 - DECIDE team - GIS group) based on primary data by OpenStreetMap.

Figure 5.7. Layout of buildings within the Vriendenerf eco-housing project. Residential units are marked with 1-12, the common building with A. Source: Vriendenerf website (https://www.vriendenerf.nl/).

Figure 5.8. Photo of the Vriendenerf eco-housing project. Source: Vriendenerf website (https://www.vriendenerf.nl/).

Building characteristics

The houses in the Vriendenerf community were built according to nearly zero-energy building standards, with a range of energy efficiency measures and high insulation standards (Label A++; Rc-values of ground floor, walls and roof 5, 5 and 6 m^2.K/Watt respectively; HR++ double glazing; Figure 5.6). This significantly reduces the energy demand of the building, allowing the required energy to be provided from the local renewable energy production via solar PV systems and heat pumps.

The buildings are connected to the municipal water and sewage networks and to the larger electricity grid, which is mandatory under Dutch law.

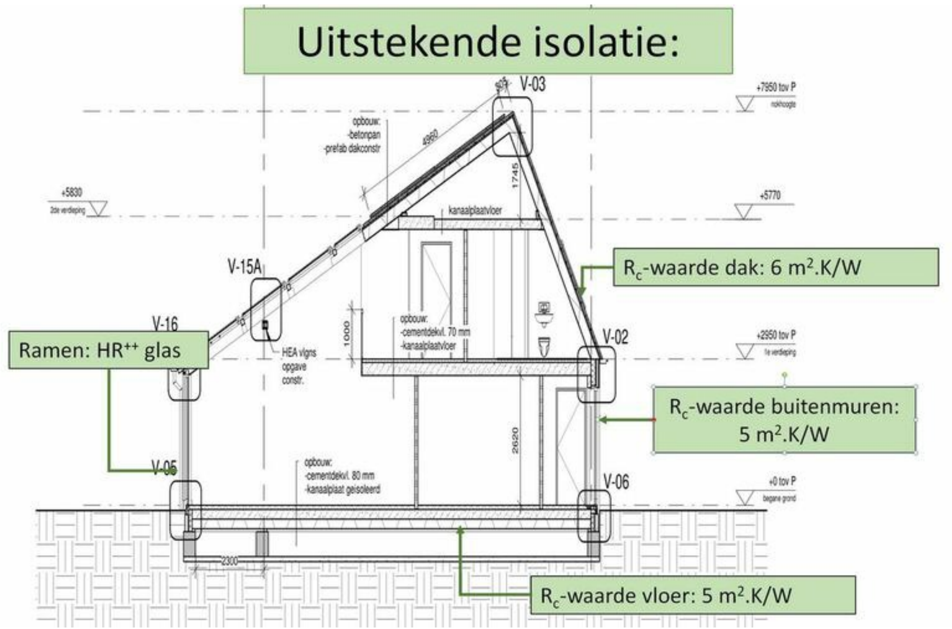

Figure 5.9. Details on building insulation in the Vriendenerf community. Source: Vriendenerf website (https://www.vriendenerf.nl/).

Energy uses

Vriendenerf is a small residential neighbourhood, with the main energy uses being domestic heating and hot water, both of which are covered by individual heat pumps in each residential unit. Electricity is used for the standard domestic uses and for the operation of the heat pumps. Some surplus electricity is used in a local EV charging station, allowing for electric mobility. As the Vriendenerf community is planning to expand its EV charging infrastructure, this energy use will likely increase in the foreseeable future.

Given that there are no commercial or industrial users with significant energy demand or complex usage patterns, the energy uses in Vriendenerf are relatively simple and easy to predict. They also provide some degree of flexibility to react to fluctuations in the local electricity production from solar PV, as community members can adjust their use of large household appliances or limit EV charging during times of low electricity production. This does, however, require the information networks to create awareness for such fluctuations and the willingness of community members to adjust their behaviour accordingly.

4.3.1.2 Social-regulatory characteristics

Social organisation

The Vriendenerf community consists of the 21 residents living within the neighbourhood. From its inception, the project was specifically designed for and by people older than 50 years. The community has formed a wide range of groups to organise daily life and various activities within Vriendenerf:

- Board of homeowners' association: Taking care of technical, legal and financial issues
- General assembly of homeowners' association: For issues such as annual budget, annual report, changes to association rules ("*huishoudelijk reglement*")
- Activity Group: For parties, interesting issues
- Shared Car group: For arranging issues about the shared car

- Common Building Group: For operating and maintenance of the common building
- Sustainability Group: Discussions and actions in the field of sustainability
- Flower Garden Group: Planning maintenance of garden
- Vegetable garden group: Planning maintenance of garden
- Maintenance Group: Organising maintenance of dwellings and installations
- PR group: Public relations and keeping a list of people with interest to live in Vriendenerf
- Vacant dwelling group: Is active when a dwelling becomes vacant
- Internal rules group: Proposing new rules to general meeting when required

All these groups consist of inhabitants, with participation being voluntary. They act when needed and report to the general meeting or in the meeting of inhabitants, and contribute to the yearly report of the association.

This wide range of groups activating community members, as well as Vriendenerf's nature as a community-driven project indicate a high level of social organisation and strong community cohesion, centred around sustainability issues.

Regulations

The current Dutch energy regulations, centered on the Gas Act and Electricity Act from 1998, do not allow communities to construct their own micro grids to share energy within the community and potentially become independent from the larger grid infrastructure. However, the Dutch energy law is currently in transition, as public consultations and the transposition of the recent EU directives 2018/2001 and 2019/944 are under way. The new Energy Act will replace the Gas Act and Electricity Act, and aims to implement new European regulations and give substance to energy-related agreements from the Dutch 2019 Climate Agreement. The specifics of the new legislation are not clear yet, including whether micro grids will be allowed under the new regulations (as of October 2022). For the time being, the inability to legally construct and operate a micro grid and to locally store energy without formally becoming an energy supplier (with all associated obligations and market regulations) are the main impediments for sharing energy within a local energy community on a peer-to-peer basis (Butenko, 2016).

The possibilities for an autarkic energy community that is unrestricted by the current energy regulations are currently explored in a number of communities benefiting from regulatory exemptions, including the Aardehuis community, which is also located in Olst and in close vicinity to Vriendenerf (Lammers & Diestelmeier, 2017).

Related to the current energy infrastructure in place in Vriendenerf, some adjustments needed to be made to abide by depth restrictions for heat pumps, related to drinking water protections. As the ground heat exchangers can only reach a maximum depth of 50m, the heat pumps installed in Vriendenerf use three to five boreholes per pump, instead of just one. This led to a slight increase in cost, but otherwise does not impede the use of heat pumps.

Formal governance

The homeowner association (Vereniging van Eigenaren / VvE) is the primary governance actor within the Vriendenerf community, comprised of the residents themselves. The VvE includes a number of decision-making bodies, including the association board, the general members' assembly and the internal rules working group, which are responsible for administrative tasks and set internal rules for community. The monthly meeting of inhabitants additionally serves as an informal platform to discuss everyday issues and gather community input.

The community has no formal relations with other organisations or actors, however, they do maintain contact with the municipality Olst-Wijhe and coordinate where needed, and interact with other communities who are interested in increasing their sustainability and self-sufficiency. In addition, community members are active in various other organisations, such as the local energy cooperative "Goed Veur Mekare," and contribute to ecological activities in the broader Olst community.

Within the SUSTENANCE project, Vriendenerf is represented by a spokesperson with personal expertise on energy infrastructures and the construction of community houses, who attends regular project meetings and provides a direct channel between individual Vriendenerf households and the other stakeholders within the SUSTENANCE project. This spokesperson also represents the community on energy issues towards the media and the public, and communicates the voices, desires and concerns of the community members.

Values and motivations

There is broad agreement among the Vriendenerf community on energy values and the motivation to be as sustainable and self-sufficient as possible. To a large degree, this is due to the nature of the Vriendenerf project, which was motivated by environmental values from the onset: the goal of the project was to provide a "house for life" for people of the age of 50+, using building techniques as environmentally friendly as possible and showing an energy performance of at least zero-energy (Vereniging Vriendenerf, 2012). Only people who agreed on these plans and values joined the initial group and later became members of the community. New potential residents are selected by the current community members to fit this profile as well.

Next to environmental values, some people also have social motivations to be part of the community, mostly related to being able to take charge of their own energy system. According to the SUSTENANCE spokesperson of the Vriendenerf community, economic motives do not play a role for the community members.

Scope of autarky aspirations

The Vriendenerf community largely prioritizes sustainability and self-sufficiency, with the goal to maximize local production beyond energy, for example by growing vegetables and fruit in the community garden. At the same time, however, there appears to be a strong vision to share the surplus of locally produced resources with the larger community around them, indicating that while self-sufficiency is desired, off-grid is not.

4.3.1.3 Energy autarky signature

The energy autarky signature for Vriendenerf (Figure 5.7) reflects the community's focus on energy efficient building standards and the coverage of energy demands by locally produced renewable energy, as well as the strong social networks and community cohesion. These strengths are in line with the origin of the Vriendenerf project as a community-led eco-housing project.

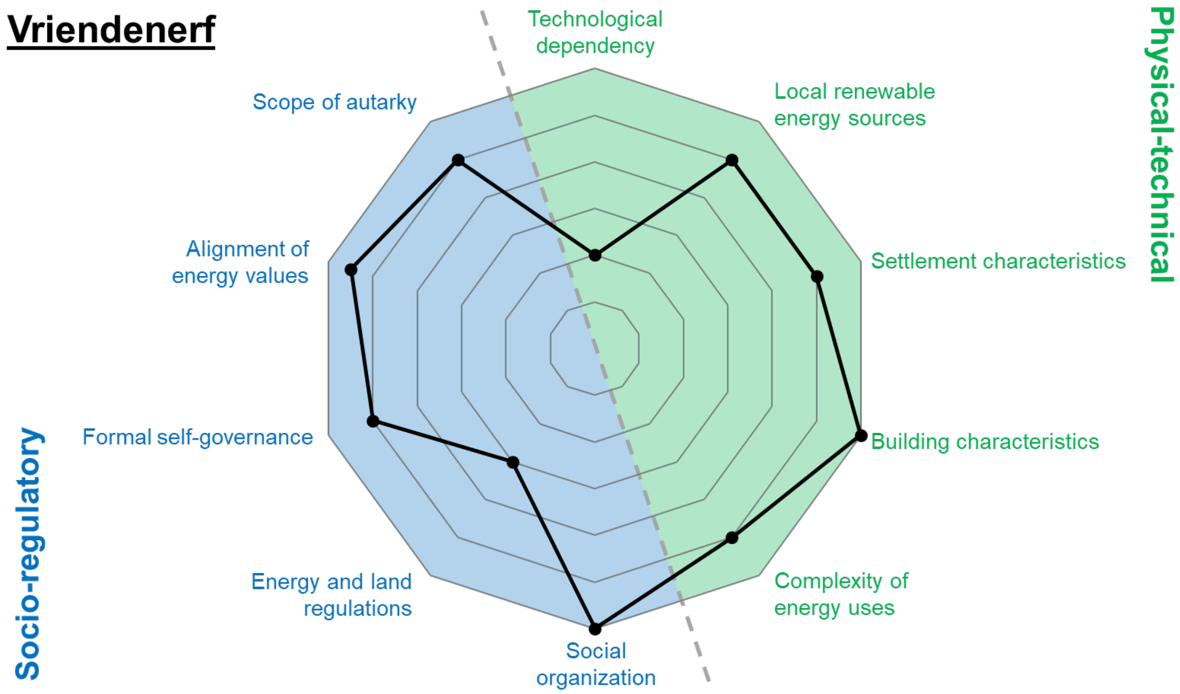

Figure 5.10. Energy autarky signature for Vriendenerf, following the SUSTENANCE typology of autarkic energy communities. Created by authors.

4.3.1.4 Key obstacles for the development of an autarkic local energy community

The Vriendenerf community is already a highly autarkic community, fulfilling its own energy demand based on local production from renewable energy sources and feeding a surplus back into the larger grid. However, within the SUSTENANCE project, the community wants to explore new ways to share energy between them. The main obstacle to this endeavor is the lack of a local micro grid within the neighborhood that allows prosumers to directly interact with each other in a peer-to-peer manner. Such a micro grid, along with the associated direct energy sharing, is currently not possible due to the *Dutch energy regulations*, which need to be considered a *limitation*, i.e., outside of the sphere of influence for the SUSTENANCE project. An exemption from the energy law might provide a way forward. At the same time, an update to the energy regulations is imminent, and more flexibility for energy communities is expected from the new legislation, in line with the EU directives on energy communities.

4.3.2 SlimPark Living Lab

SlimPark on the University of Twente campus in Enschede is a self-sufficient EV charging station, powered by a 27 kWp solar panel rooftop and equipped with battery storage. It is a living lab used by researchers to study self-sufficient energy systems and user interactions with the system, and will be used to explore new methods of direct interaction between user and energy system, e.g., via innovative apps or business models.

4.3.2.1 Physical-technical characteristics

Technological dependence

SlimPark is outfitted with its own micro electricity grid for distribution within the project area. The micro grid is connected to the larger campus grid of the University of Twente, for which the university itself acts as distribution system operator (DSO). The local energy infrastructure allows the SlimPark grid to internally balance the locally produced electricity and the EV charging stations, combined with a battery for electricity storage (capacity 30 kWh / 10 kW).

One of the objectives of the SlimPark project is to minimize grid usage of the combined assets. Having both its own micro grid and, for the time being, sufficient electricity storage capacity via the local battery supports this objective.

Local renewable energy resources

The SlimPark roof is fully covered with a solar PV system with 27 kWp installed capacity, serving the nine EV charging spots included in the project. This is currently sufficient to cover the electricity demand of the project, due to the combination with electricity storage and a smart charging system. However, the PV system alone would not be able to supply sufficient electricity if all nine EV charging stations were to request full power at the same time.

No expansion of the solar PV system is planned at the moment.

Settlement characteristics

SlimPark is a small EV charging station of 0.1 ha, including with nine parking spots. It is located on the suburban University of Twente campus, in between the cities of Enschede and Hengelo. The campus includes a number of educational and research facilities, alongside residential and commercial buildings linked to the university community, with plenty green spaces around and between the low- to mid-rise buildings (Figure 5.8, Figure 5.9).

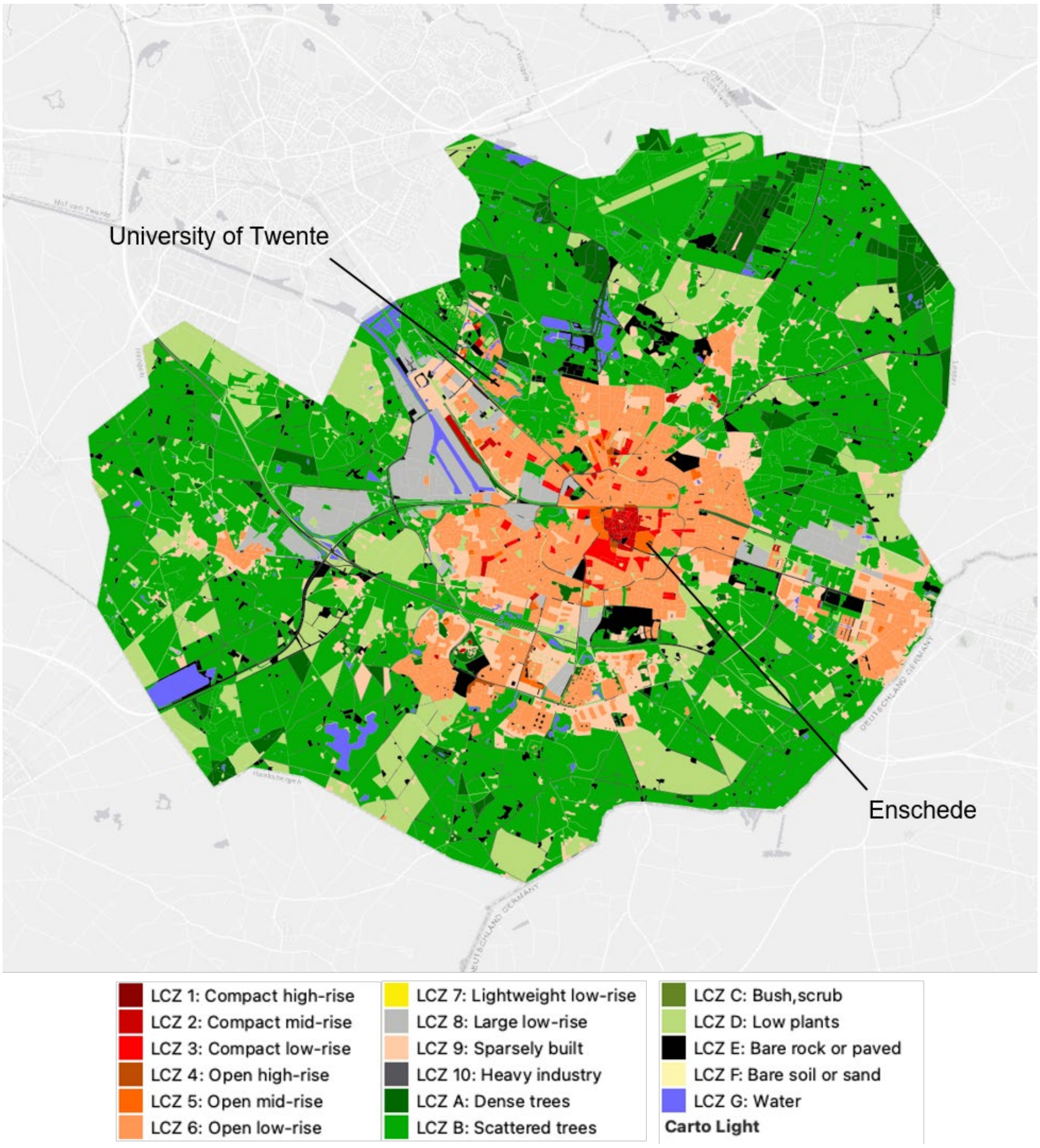

Figure 5.11. Local Climate Zone (LCZ) map of Enschede municipality, indicating built-environmental configurations surrounding the University of Twente campus area. Produced with the Geoclimate algorithms of Lab-STICC (CNRS UMR 6285 - DECIDE team - GIS group) based on primary data by OpenStreetMap.

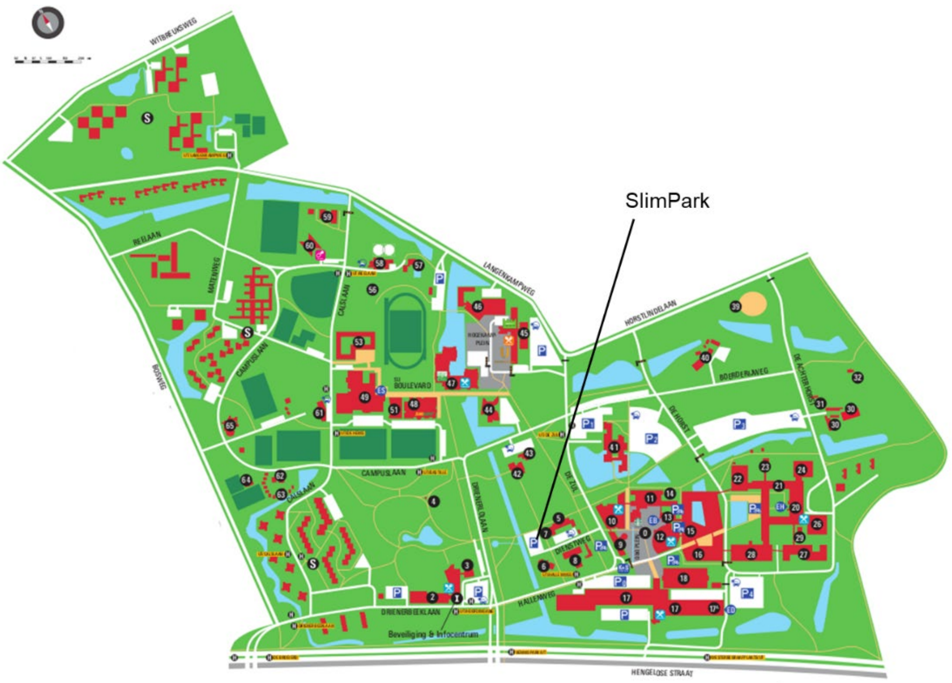

Figure 5.12. Location of the SlimPark project site on the University of Twente campus. Base map: University of Twente (https://www.utwente.nl/en/et/tfe/research-groups/MSM/documents/campusmap.pdf).

Building characteristics

There are no significant building characteristics to consider for the SlimPark project, as it is a carport with no closed building spaces, apart from a small support office attached to the solar roof. The carport itself is constructed in a very minimalistic design, as shown in Figure 5.10.

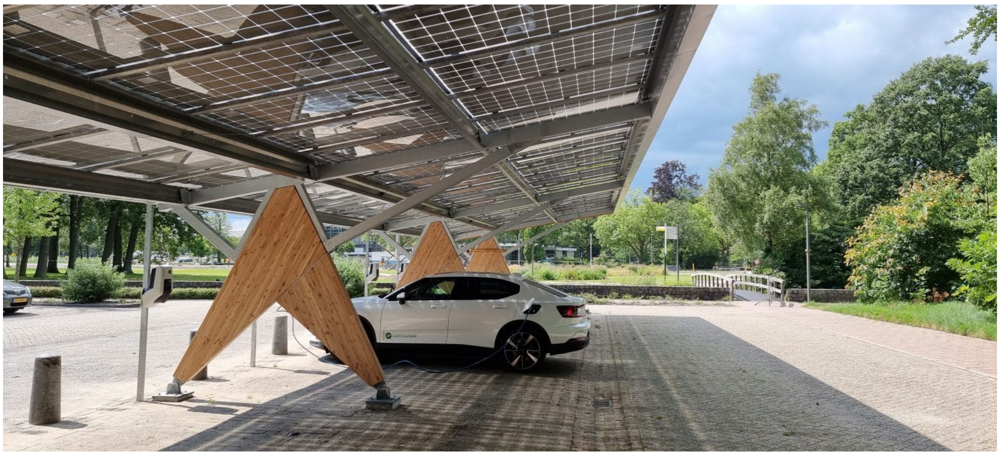

Figure 5.13. SlimPark solar carport. Source: AmperaPark website (https://amperapark.com/nl/projecten/universiteit-twente/)

Energy uses

The primary electricity use at SlimPark is for e-mobility, with nine EV chargers (22 kW AC). A small office building is attached to the carport, which is also supplied with electricity from the PV panels.

The available electricity storage in combination with the flexible use of the EV charging stations provides SlimPark with the ability to react to fluctuations in the local electricity production by adjusting the amount of electricity used to charge the parked vehicles. Part of the SlimPark living lab research projects indeed focuses on developing models to optimize the allocation of electricity based on local production and storage availability.

4.3.2.2 Social-regulatory characteristics

Social organisation

Users of the EV charging facilities are registered participants in the SlimPark project. They participate in the project by charging their electric cars while using a specifically prepared smartphone app to indicate available energy flexibility. The current cohort of users act as a test group within the living lab setting. At present, there is no information available on the characteristics of these users (e.g., socio-economic status, motivations to drive an electric vehicle), and the SlimPark research team is currently designing a survey to gather this data.

Specific social networks and organisational structures within the SlimPark project will most likely depend on the experiments with user interaction and different business models throughout the SUSTENANCE project. This includes considerations of whether the SlimPark project will be connected to the wider University of Twente community, or remain a mostly stand-alone project with some university community members being users/customers.

Regulations

As SlimPark is located within the grid of the University of Twente campus, with the university acting as its own distribution system operator, it has more regulatory flexibility than other projects. In addition, the carport is small enough to operate 'behind the meter,' i.e., to be considered as one energy user, rather than combining different users as would be the case for projects including different residential units with separate connections to the grid. This gives SlimPark the ability to easily share energy between different PV installations and EV chargers within its own micro grid, without having to abide by the kinds of energy regulations that apply to larger-scale projects with several metered energy users.

Formal governance

There are two kinds of relationships between the SlimPark project team and other actors that are important to consider from a governance perspective.

First, the relationship between project team and users. Users need to register via the project website (https://twente.energy/)[4], according to the rules determined by the project team. Users can then provide feedback and share their experiences to the project team, which accounts for these inputs in the further development of the SlimPark project.

Second, the relationship between project team and external partner organisations. The key partners engaged in the SlimPark project are the University of Twente as owner of the carport and the local

[4] As of September 2022, the project is not accepting new registrations as it has reached the maximum number of participants. Interested EV owners can request to be added to the waiting list.

distribution system operator (within the campus), and the private businesses that supply technology to the project, namely AmperaPark, Mennekes and Kiwatt. The cooperation with these partners is in the context of different research projects, where project and data contracts describe the rules of interaction and the responsibilities of each actor.

Governance in the SlimPark project is therefore primarily formal and clearly defined in project contracts or user agreements. The research team is at the center of the governance system, while also dependent on the collaboration with external partners and the SlimPark users. At present, there is little community influence in shaping governance mechanisms.

Values and motivations

As of now, there is no information on the values and motivations of different users to participate in the SlimPark project or to use an electric vehicle yet. The research team is currently preparing to conduct a survey to fill this knowledge gap and learn more about the social profiles of the SlimPark users.

The research projects linked to SlimPark generally try to combine ecological and economic motives, trying to develop new technologies and management configurations that both decrease carbon footprints and create economic value.

Scope of autarky aspirations

SlimPark is designed as a fully autarkic EV charging station, i.e., with the goal to not use any electricity outside of what is produced on site.

4.3.2.3 Energy autarky signature

The SlimPark carport was specifically designed and built to be a self-sufficient EV charging station, meaning the relevant physical-technical characteristics to support such an energy system were part of the design process from the beginning. The autarky signature for SlimPark (Figure 5.11) reflects this, as well as the relatively limited work on social dynamics surrounding the project so far.

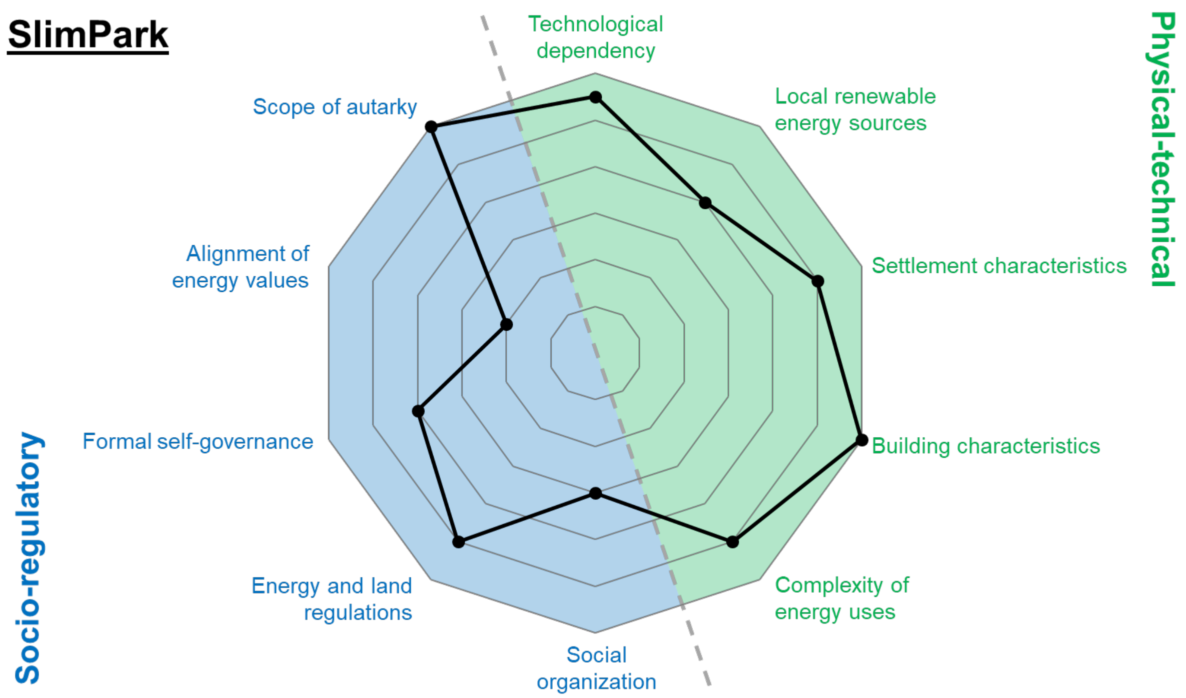

Figure 5.14. Energy autarky signature for the SlimPark Living Lab, following the SUSTENANCE typology of autarkic energy communities. Created by authors.

4.3.2.4 Key obstacles for the development of an autarkic local energy community

The current lack of information on key social aspects of the project, particularly on the characteristics of the users (e.g., motives, socio-economic status, technological acceptance) limits the opportunities for community-building around SlimPark. So far, the main actors engaged with SlimPark are the researchers and partner organisations or businesses that are involved with different research projects and construction of the carport, with their roles and interactions clearly defined by project contracts.

If the goal is to more actively involve users in the SlimPark project and potentially build a community of users around the charging station, the main *challenge* will be to gather this missing data on user characteristics, including *energy values*, and to develop suitable *social organisation* models. The SlimPark research team is currently in the process of developing a user survey, which will provide important insights in this regard. The project's registry of users and the project app as communication platform are a valuable resource in reaching out to the users. The question of how many users can be part of the SlimPark project will need to be addressed as well, considering that it is currently not possible to sign up for the service and become part of the potential project community.

4.4 Poland

4.4.1 Mickiewicza Street

The demo site in Poland focuses on Własnościowa Spółdzielnia Mieszkaniowa (WSM), a housing cooperative in Mickiewicza Street in Sopot, comprising five residential apartment buildings and one commercial building. Within the housing community, a micro grid-based integrated local energy system will be developed, that aims to include solar PV systems and heat pumps, as well as battery storage and EV installations. Smart control, monitoring and management systems will be applied to optimize the operation of the local system. As a first step, the SUSTENANCE project focuses on one apartment building, building number 59.

4.4.1.1 Physical-technical characteristics

Technological dependence

The buildings in WSM are partially integrated into the larger electricity grid via a substation across the street (see Figure 5.14), and each apartment unit has its own meter. Electricity is supplied to the buildings by Energa Operator, which is part of the SUSTENANCE project team.

Gas is provided by the Polish Oil Mining and Gas Extraction S.A. company (PGING) via the regular gas grid as well, directly to each apartment with its own gas meter. As there is no direct supply of hot water to the apartments, each unit uses a gas oven to heat water individually.

There are currently no storage facilities for electricity or gas available within the project area, making both supply and storage of energy dependent on the larger grids.

Local renewable energy resources

WSM currently does not produce any energy from renewable sources. Over the course of the SUSTENANCE project, a PV system with an estimated capacity of 24.4 kWp will be installed on the roof of Building 59, with an expected annual electricity production of 20 MW.

Similar installations would eventually be installed on the other four apartment buildings as well. It is yet unclear whether this is sufficient to cover the overall energy use of all buildings (see section on energy uses).

Settlement characteristics

The WSM site is located on the western edge of Sopot, a city of ca. 35,000 inhabitants located in between the larger cities of Gdańsk and Gdynia (the 'Tricity' area). To the west, the project area is bordered by forest, most of which is protected as a nature reserve. Within the urban area, the project site is surrounded by low density residential properties with detached or semi-detached houses, making the eleven-story apartment buildings visually stand out (Figure 5.12, Figure 5.13).

The project area of the WSM comprises five residential apartment buildings and one commercial building (Figure 5.14), connected by green spaces and walking paths. This provides ample space for the development of additional small-scale energy infrastructure within the project area if needed.

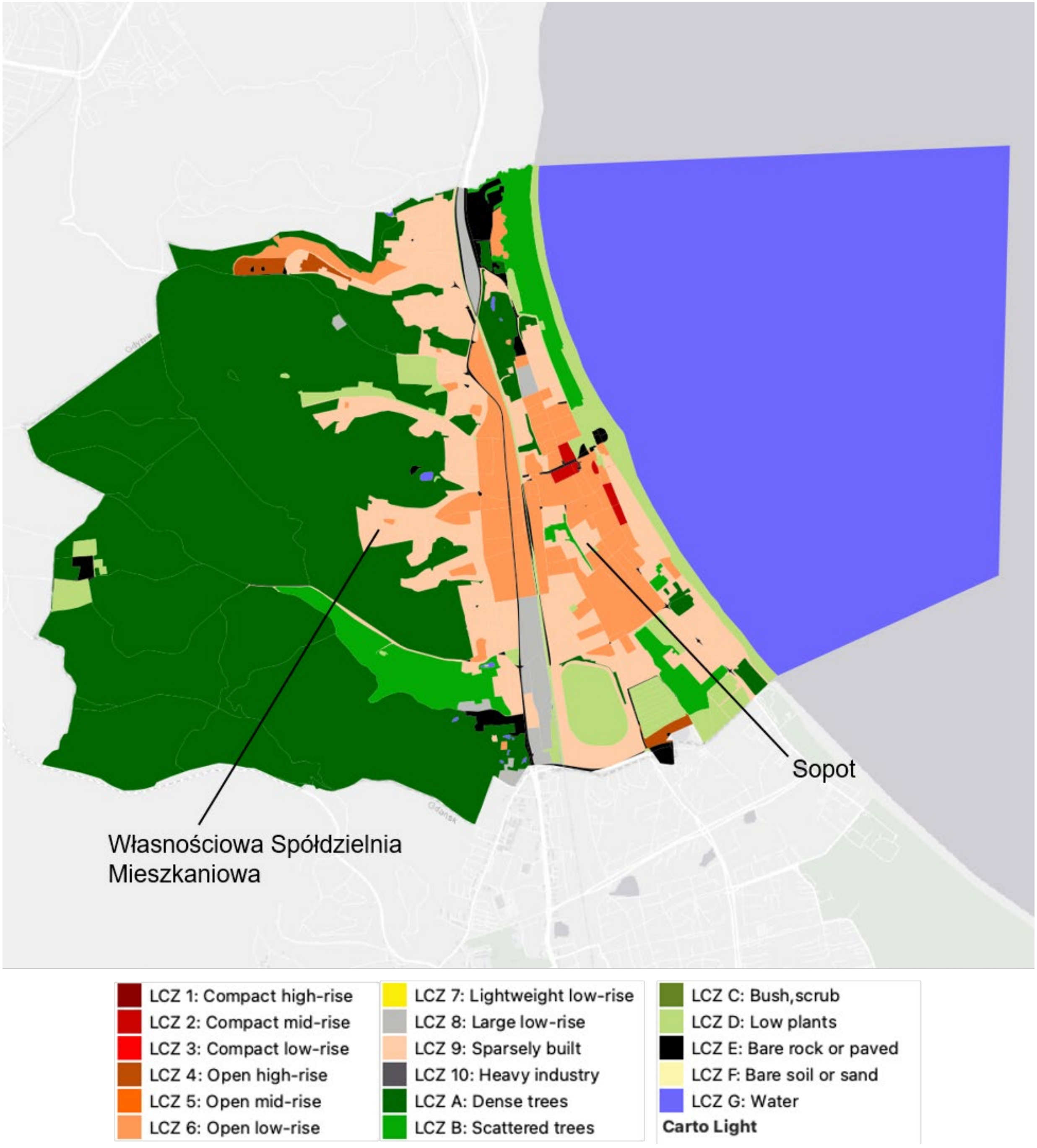

Figure 5.15. Local Climate Zone (LCZ) map of Sopot municipality, indicating built-environmental configurations surrounding the Mickiewicza Street demo site. Produced with the Geoclimate algorithms of Lab-STICC (CNRS UMR 6285 - DECIDE team - GIS group) based on primary data by OpenStreetMap.

Figure 5.16. View of the WSM site, including buildings 57, 59 and 61 (from left to right). Photo by Czesław Piechnik, via WSM website (www.wsmsopot.jimdofree.com).

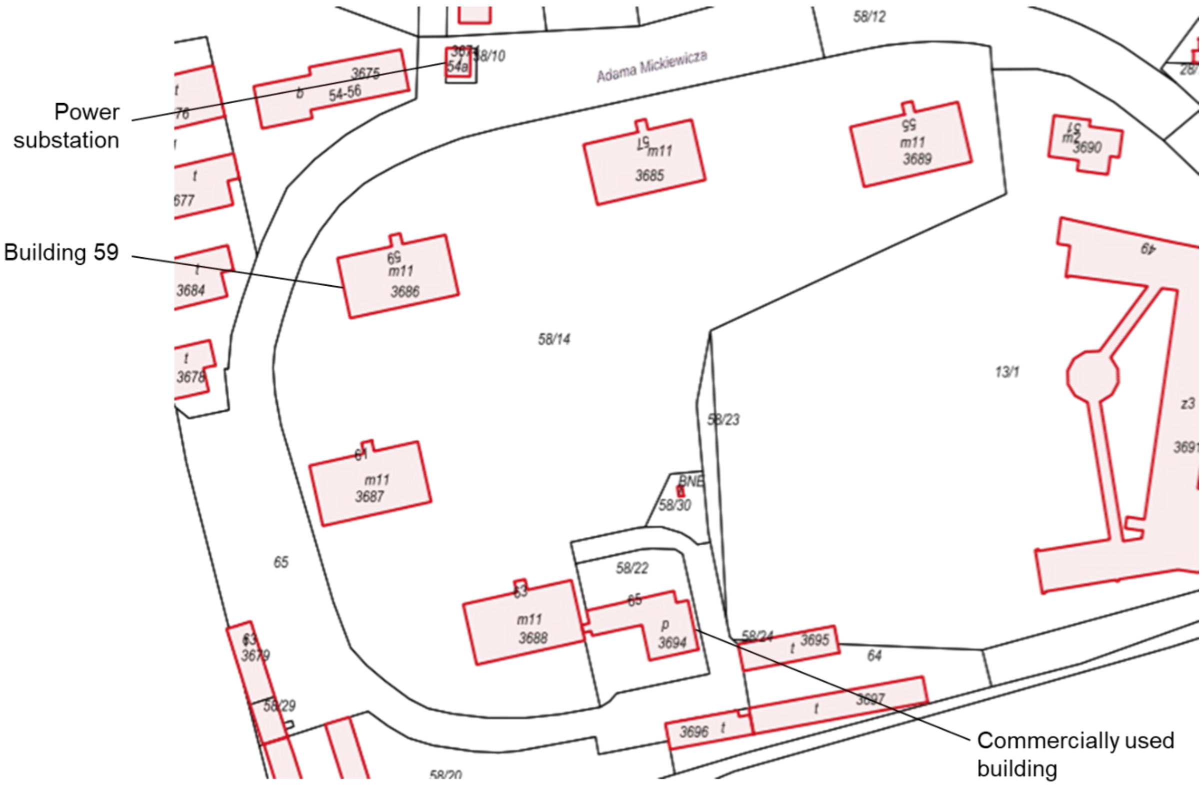

Figure 5.17. Layout of the Własnościowa Spółdzielnia Mieszkaniowa (WSM) housing cooperative, including five residential apartment buildings (numbers 55, 57, 59, 61, 63) and one commercially used building (number 65). Building 59 acts as pilot case within the demo site.

Building characteristics

Each apartment building is eleven storeys tall, built from concrete and insulated with polystyrene in the early 1970s. Water and wastewater services are provided by the municipality via the public network, however, the water pressure in the municipal network is not sufficient to reach the upper floors of the buildings. Instead, water is sent via a local hydrophore system for the upper floors, which makes the modernization of the domestic hot water system somewhat more complicated.

The 77 apartments in the Building 59 are currently heated (incl. hot water) by individual gas boilers. These will be replaced with central heating based on an air heat pump, which will also require the abovementioned modernization of the hot water system, as water is currently heated via the gas boilers within each unit.

Energy uses

The primary energy uses in WSM are domestic, as most units are residential apartments. Within each flat, some energy is needed for common areas, including elevators and staircases. For the pilot building 59, this amounts to ca. 5400 kWh per year, based on data from 2018-2021. Additional electricity is needed for the commercial building and to light the walking paths within the project area, as well as for the hydrophore system to pump water to the upper floors of the buildings (ca. 9695 kWh per year).

As part of SUSTENANCE, options for EV charging within the premises of WSM will be explored, adding another energy use.

4.4.1.2 Social-regulatory characteristics

Social organisation

Across all five apartment buildings, the project area along Mickiewicza Street houses several hundred households, giving the demo site a relatively large community. However, there is no indication of significant social cohesion or social life within the community. The housing cooperative itself is primarily concerned with the facility management and daily logistics of the buildings, but does not seem to offer social activities or platforms for informal dialogue among tenants. There do not seem to be any specific activities related to energy or sustainability either.

Regulations

The Polish energy regulation landscape is currently undergoing significant changes, with new legislation introduced very recently and the transposition of EU directives still ongoing. This has resulted in a number of inconsistencies within and between new energy regulations, and many uncertainties still remain. As part of the SUSTENANCE project, WSM and its project partners want to explore the legal possibilities of establishing an energy community for the cooperative.

Formal governance

The housing cooperative Własnościowa Spółdzielnia Mieszkaniowa (WSM) is the central governance actor in this demo site. It is led by a management board and a supervisory board and includes a number of committees in charge of different tasks related to facility management. The General Members Assembly is WSM’s highest decision-making body, allowing community members to voice their opinions and to vote on the boards and other relevant decisions. The cooperative has a set of statutes and regulations that govern life in the WSM flats, related to conduct towards other tenants, water and energy supply, waste management, fire protection, and others. These regulations are available via the website (https://wsmsopot.jimdofree.com/dokumenty).

Within SUSTENANCE, project partners next to WSM include the Institute of Fluid-flow Machinery at the Polish Academy of Sciences (IMP), the energy supplier Energa Operator, and the companies KEZO and STAY-ON, both of which are involved in the provision and management of new energy system technology.

Values and motivations

The primary motivation for WSM's move towards renewable energy generation and autarky is economic, i.e., to reduce energy costs. There is broad agreement on this within the community. At the same time, ecological motivations have become more common as well, and the community considers 'going green' as an important step and wants to set an example locally.

Scope of autarky aspirations

While the main focus of the demo site is on the economic benefits of local energy production from RES, the idea of being a local frontrunner for ecological energy transitions could be an entry point for further development in the direction of autarky.

4.4.1.3 Energy autarky signature

The energy autarky signature for the WSM project site in Mickiewicza Street (Figure 5.15) reflects the challenge of retrofitting a 1970s apartment building. There are strong governance mechanisms in place surrounding the housing cooperative WSM, and tenants agree on pursuing the transition towards cheaper energy from RES, which can be used as starting points for community-building within the project area. While there is currently no local energy production from RES, resulting in a low score on the RES criterion, extensive PV installations are planned as part of the retrofitting process.

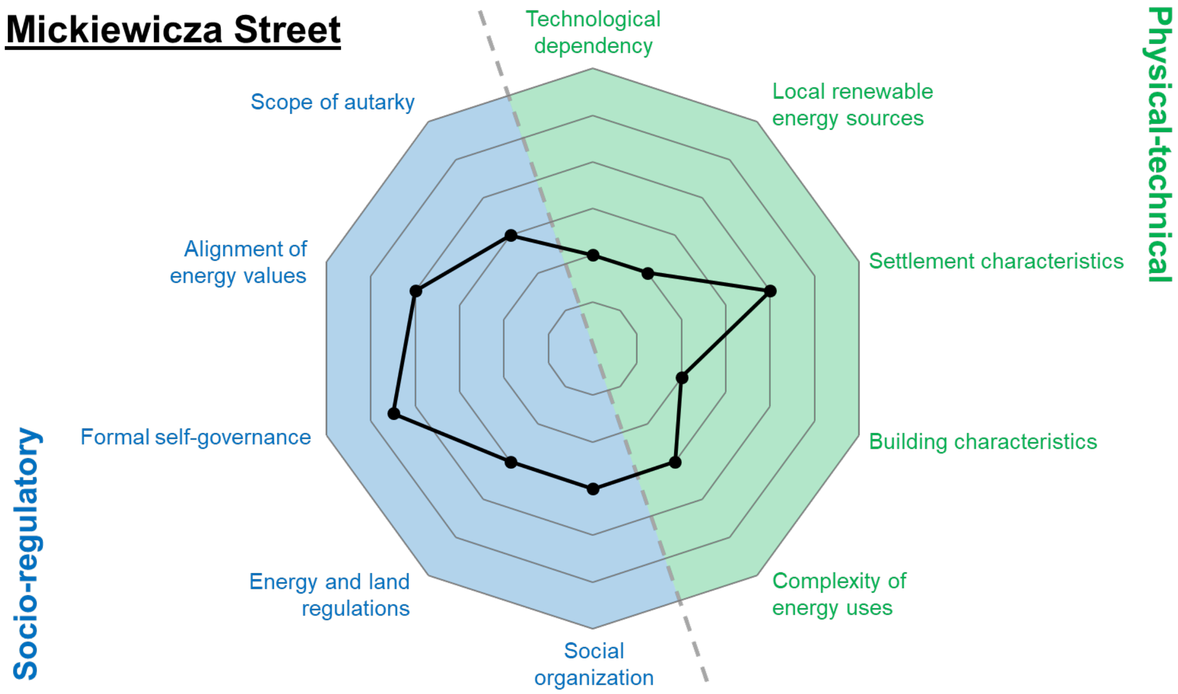

Figure 5.18. Energy autarky signature for the WSM project site in Mickiewicza Street, following the SUSTENANCE typology of autarkic energy communities. Created by authors.

4.4.1.4 Key obstacles for the development of an autarkic local energy community

A key *challenge* for the WSM project site are the relatively *complex energy uses.* In combination with the overall infrastructure state and the, as of now, low local energy production, this will require careful and smart energy management. Technical innovations can provide some entry points and solutions, however, collaboration among residents, for instance to coordinate the use of large household appliances, might be needed in order to achieve a high degree of self-sufficiency as well. In this context, the current lack of *social organisation* beyond the housing cooperative itself will present a *challenge* to community-building.

The uncertainty related to *energy regulations* is currently a *limitation* for any local energy transition project in Poland.

5 Site comparison

The seven demo sites within the SUSTENANCE project cover a range of contexts and starting conditions for the development of autarkic energy systems based on renewable energy sources. The side-by-side comparison of the different autarky signatures (Figure 6.1) shows similarities and differences between the sites. Based on project characteristics, three groups can be distinguished:

1) European residential sites, which focus on existing, electrified neighbourhoods switching to more renewable energy sources and a higher degree of self-sufficiency;

2) Indian residential sites, which focus on existing villages of varying degrees of electrification, with the goal to improve electrification by building on renewable energy sources and autarky principles; and

3) Electric mobility sites, which focus on self-sufficient EV charging systems powered by local energy production from RES.

Differences in the conditions of local energy infrastructure – linked to the typology characteristics of technological dependency, settlement characteristics and building characteristics – reflect the diverse development processes of the different demo sites. The three European residential demo sites and two Indian residential demo sites all need to be retrofitted with new micro grids to allow for the development towards an autarkic energy community. Such decentralized energy infrastructure was either not a consideration when the neighbourhoods were first built (in the case of Voerladegård and Mickiewicza Street), not legally possible (in the case of Vriendenerf) or not yet in place at all (in the cases of Barubeda and Borakhai). New developments with a specific focus on autarky from the start, like SlimPark and partially the IIT Bombay campus, on the other hand can include such energy infrastructure in the initial project design and construction.

Most demo sites come with one primary energy use and a relatively low complexity of different uses in the local system, with domestic uses and EV charging allowing for some degree of flexibility with regards to electricity use. Although, while in the Indian residential demo sites the energy use for domestic load is at a very basic level – particularly compared to the European demo sites, limited energy supply requires optimized control and flexibility, and careful management of available energy resources, presenting its own challenges related to complexity of the local system. Nevertheless, the case of WSM in Mickiewicza Street stands out as the most complex case, combining domestic and commercial uses as well as lighting of public spaces and the operation of shared spaces within the buildings. This will require a more careful management of the available energy resources and might increase the need for local energy storage.

In the socio-regulatory dimension, the European residential sites can build on existing governance structures and social organisation platforms linked to village and neighbourhood associations, giving them a strong social foundation for the development of more autarkic energy systems. It should be noted that for all European sites, the current shift in energy regulations can provide many opportunities for the development of local energy communities, but also brings a significant amount of uncertainty until all policy development surrounding the transpositions of the EU's revised Renewable Energy

Directive (2018/2001) and Internal Electricity Market Directive (2019/944) are finalized in all project countries.

In comparison, the Indian demo sites seem to have less social foundation for the development of more autarkic energy systems. Public organizations seem to dominate the existing governance structures, while residents or other users of the energy systems are not formally represented. Only in the demo site of Borakhai, villagers are socially organized in a Village Energy Committee (VEC). Moreover, the SUSTENANCE project in India has to comply with energy and land regulations that are set at the national level, limiting the degree of freedom to experiment and implement local solutions independently. Yet, compared to the European demo sites, regulations at the Indian state level might be better fitted to the local conditions of the Indian demo sites, compared to overarching European regulations for the Polish, Dutch and Danish demo sites. However, this requires further study.

With regards to energy values in the different project communities, there is a split between sites primarily motivated by economic motives (i.e., lowering energy costs) and sites primarily motivated by environmental motives (i.e., reducing carbon emissions in the energy sector). However, within each project community, there is generally agreement on the primary motivation. This alignment of values within the community is conducive to the development towards a more autarkic, renewable energy system. At the same time, the difference in primary motivations needs to be considered when designing interventions within SUSTENANCE, to ensure acceptance by the different project communities.

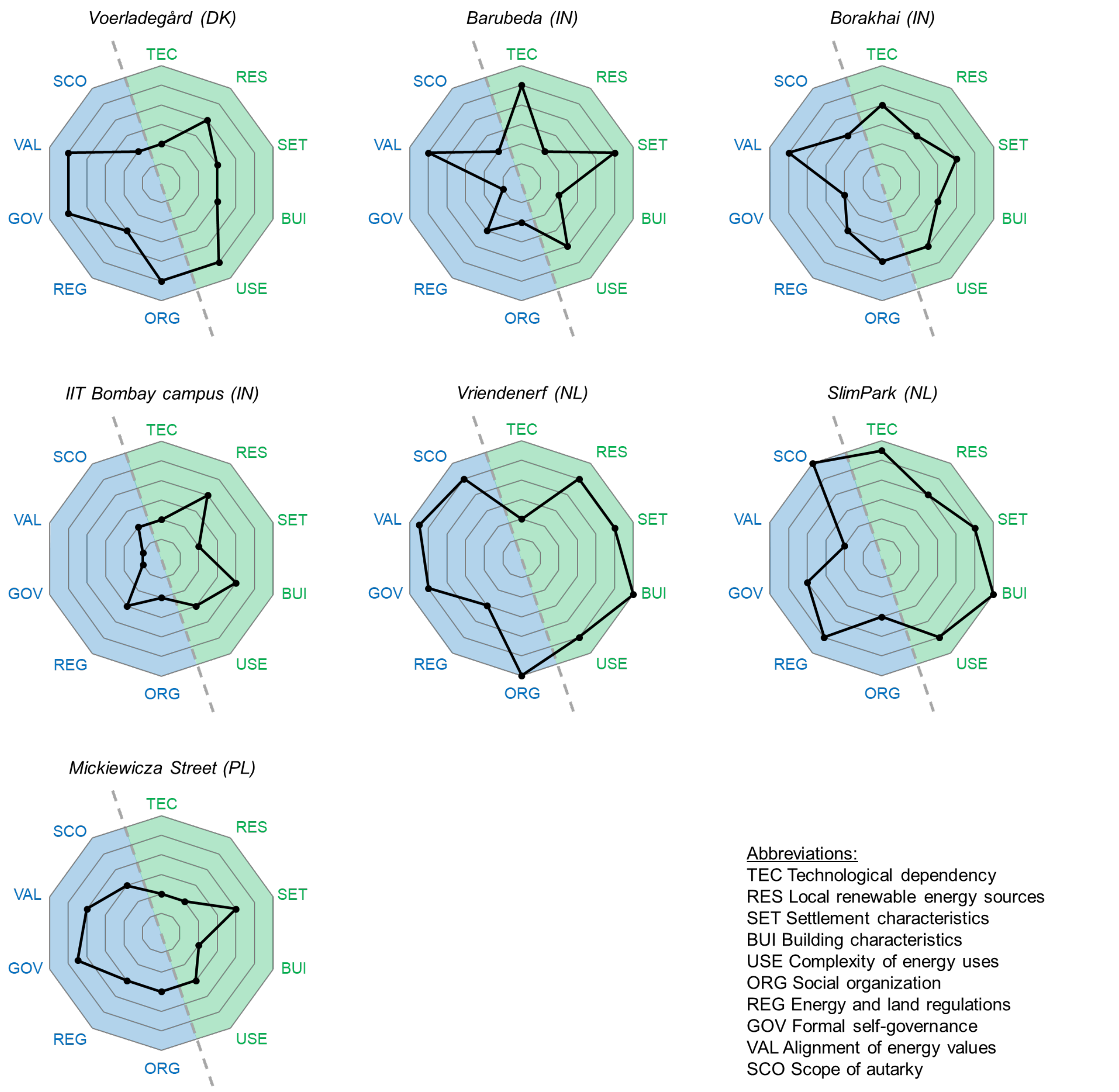

Figure 6.1. Side-by-side comparison of the autarky signatures of the seven SUSTENANCE demo sites. Created by authors.

The range of starting conditions for SUSTENANCE among the demo sites corresponds to a variety of obstacles that may hinder the development towards higher degrees of autarky in the different cases. Table 6.1 provides an overview of the key obstacles identified in each demo site.

While each case includes one or more obstacles that need to be overcome to fully realize the demo site's potential as an autarkic energy community, most of these obstacles are challenges that can be solved within the community and the local energy system (the 'niche'), rather than limitations that force the local energy system to adjust to external conditions (e.g., energy regulations). This implies that targeted interventions within the SUSTENANCE project can help overcome the key obstacles in most cases. Next to technical interventions to address shortcomings in the physical-technological dimension, this also includes social interventions that provide new organisational configurations to manage the local energy system, support community-building surrounding the local energy system and identify opportunities for local energy system transition within the confines of the current energy regulations where needed. A more detailed analysis of such potential solutions based on the obstacles identified for each demo site in this report is included in the follow-up SUSTENANCE project deliverable D3.2.

Table 6.1. Key obstacles for the development of more autarkic energy systems in the different SUSTENANCE demo sites, as identified in this report.

Demo site	Key obstacles	Type of obstacle
Voerladegård (DK)	Physical-technical dimension	Challenge
Barubeda (IN)	Local RES, social organisation, self-governance	Limitation, challenge, challenge
Borakhai (IN)	Local RES, social organisation	Limitation, challenge
IIT Bombay campus (IN)	Social organization, self-governance	Challenge
Vriendenerf (NL)	Energy regulations	Limitation
SlimPark (NL)	Energy values, social organisation	Challenge
Mickiewicza Street (PL)	Complexity of energy uses, social organisation	Challenge

6 Conclusions

This report analysed the socio-technical conditions in the seven SUSTENANCE demo sites, with the goal to identify obstacles that hinder the development and operation of autarkic local integrated energy systems. The results as outlined in the previous sections carry several implications for the SUSTENANCE project and the interventions that are designed and implemented in each individual demo site.

First, there are significant differences between the energy infrastructures and energy efficiency of the built environments in each demo site, as the sites range from a recently-built eco-housing community over 1970s apartment buildings to remote non-electrified villages. Many of these technical characteristics will be the focus of technological interventions throughout SUSTENANCE. In each case, it will be important to consider why the required infrastructure for a more autarkic energy system is not yet in place, and whether there are social dimensions to it, such as in the case of Vriendenerf, where a micro grid has not yet been possible under Dutch energy regulations.

Second, while smart energy management systems are a key component of the SUSTENANCE project in all demo sites, successful management, particularly on the demand side, will also require a willing community. Strengthening social organisation and community-building might therefore be required in some cases to ensure the buy-in and active participation of community members.

Third, the design of project interventions needs to be mindful of the predominant energy values and motivations within each demo site community, and provide incentives accordingly. This primarily relates to the difference between economic motivations in some cases, where the main incentive is a lower energy bill, and environmental motivations in other cases, where the main incentive is to lower the carbon footprint of the local energy system. These motivations also influence the degree to which a community is striving for autarky, whereby environmentally-minded communities are generally more likely to aspire a higher degree of autarky than might be cost-effective.

Finally, while this report analysed the various socio-technical characteristics of each demo site as separate elements, it is important to remember that they are inherently connected and interact with each other. The amount of renewable energy that needs to be produced within the local energy system depends on the usage patterns and storage capacity of the system, with energy demand being closely related to the energy efficiency of buildings. Settlement and building characteristics may be determined by land and energy regulations, such as land use and zoning plans or insulation standards. As a consequence, there are a wide range of possible solutions to the obstacles identified in this report, including both technological and social interventions.

The impact of the different SUSTENANCE interventions on the characteristics of each demo site and on its development towards a more autarkic energy system will provide new insights on the dynamic development of local energy systems and the co-evolution of technical and social elements. This report, being the first deliverable of SUSTENANCE WP3, set the scene for such an analysis throughout the project. Specifically, it provides a framework for determining the impacts of technical and social innovations in (more) autarkic local energy systems as part of SUSTENANCE work package 8. More details on possible interventions to address the obstacles in each demo site, and on the overall analytical framework to track the progress of the different demo sites towards a higher degree of autarky, are included in the follow-up deliverables D3.2 and D3.3, respectively.

7 References

Ackoff, R. L. (1994). Systems thinking and thinking systems. *System Dynamics Review*, *10*(2-3), 175–188. https://doi.org/10.1002/sdr.4260100206

Bossi, S., Gollner, C., & Theierling, S. (2020). Towards 100 Positive Energy Districts in Europe: Preliminary Data Analysis of 61 European Cases. *Energies*, *13*(22), 6083. https://doi.org/10.3390/en13226083

Bouw, K., Wiekens, C., Elbert, S., & Faaij, A. (2022). How to plan for success? An exploration of social context factors in neighbourhood energy planning. *Energy Research & Social Science*, *92*, 102761. https://doi.org/10.1016/j.erss.2022.102761

Butenko, A. (2016). Sharing Energy: Dealing with Regulatory Disconnection in Dutch Energy Law. *European Journal of Risk Regulation*, *7*(4), 701–716. https://doi.org/10.1017/S1867299X00010138

Chilvers, J., Pallett, H., & Hargreaves, T. (2018). Ecologies of participation in socio-technical change: The case of energy system transitions. *Energy Research & Social Science*, *42*, 199–210. https://doi.org/10.1016/j.erss.2018.03.020

Creamer, E., Eadson, W., van Veelen, B., Pinker, A., Tingey, M., Braunholtz-Speight, T., Markantoni, M., Foden, M., & Lacey-Barnacle, M. (2018). Community energy: Entanglements of community, state, and private sector. *Geography Compass*, *12*(7), e12378. https://doi.org/10.1111/gec3.12378

D'Alpaos, C., & Andreolli, F. (2021). Renewable Energy Communities: The Challenge for New Policy and Regulatory Frameworks Design. In C. Bevilacqua, F. Calabrò, & L. Della Spina (Eds.), *New Metropolitan Perspectives: Knowledge Dynamics and Innovation-driven Policies Towards Urban and Regional Transition Volume 2* (pp. 500–509). Springer. https://doi.org/10.1007/978-3-030-48279-4_47

Devine-Wright, P. (2007). Energy Citizenship: Psychological Aspects of Evolution in Sustainable Energy Technologies. In J. Murphy (Ed.), *Governing Technology for Sustainability* (pp. 63–86). Routledge.

Dóci, G., & Vasileiadou, E. (2015). "Let's do it ourselves" Individual motivations for investing in renewables at community level. *Renewable and Sustainable Energy Reviews*, *49*, 41–50. https://doi.org/10.1016/j.rser.2015.04.051

Ecker, F., Hahnel, U. J. J., & Spada, H. (2017). Promoting Decentralized Sustainable Energy Systems in Different Supply Scenarios: The Role of Autarky Aspiration. *Frontiers in Energy Research*, *5*, Article 14, 11. https://doi.org/10.3389/fenrg.2017.00014

European Commission. (n.d.). *Energy Communities Repository: Energy Communities*. Retrieved August 8, 2022, from https://energy-communities-repository.ec.europa.eu/energy-communities_en

European Commission. (2019). *The European Green Deal*. COM(2019) 640. Brussels. https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_1&format=PDF

European Commission. (2020). *Powering a climate-neutral economy: An EU Strategy for Energy System Integration*. COM(2020) 299. Brussels. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0299&from=EN

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, *31*(8-9), 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8

Givoni, B. (1998). *Climate Considerations in Building and Urban Design*. John Wiley & Sons, Ltd.

Hauber, J., & Ruppert-Winkel, C. (2012). Moving towards Energy Self-Sufficiency Based on Renewables: Comparative Case Studies on the Emergence of Regional Processes of Socio-Technical Change in Germany. *Sustainability*, *4*(4), 491–530. https://doi.org/10.3390/su4040491

Hess, D. J., & Coley, J. S. (2014). Wireless smart meters and public acceptance: The environment, limited choices, and precautionary politics. *Public Understanding of Science (Bristol, England)*, *23*(6), 688–702. https://doi.org/10.1177/0963662512464936

Holling, C. S. (2001). Understanding the Complexity of Economic, Ecological, and Social Systems. *Ecosystems*, *4*(5), 390–405. https://doi.org/10.1007/s10021-001-0101-5

Homan, B., Hoogsteen, G., Nebiolo, S., Hurink, J. L., & Smit, G. J. M. (2019). Maximizing the degree of autarky of a 16 house neighbourhood by locally produced energy and smart control. *Sustainable Energy, Grids and Networks*, *20*(3), 100270. https://doi.org/10.1016/j.segan.2019.100270

Hoppe, T., Graf, A., Warbroek, B., Lammers, I., & Lepping, I. (2015). Local Governments Supporting Local Energy Initiatives: Lessons from the Best Practices of Saerbeck (Germany) and Lochem (The Netherlands). *Sustainability*, *7*(2), 1900–1931. https://doi.org/10.3390/su7021900

Lammers, I., & Diestelmeier, L. (2017). Experimenting with Law and Governance for Decentralized Electricity Systems: Adjusting Regulation to Reality? *Sustainability*, *9*(2), 212. https://doi.org/10.3390/su9020212

Li, F. G.N., Trutnevyte, E., & Strachan, N. (2015). A review of socio-technical energy transition (STET) models. *Technological Forecasting and Social Change*, *100*(Suppl. 3), 290–305. https://doi.org/10.1016/j.techfore.2015.07.017

Lwasa, S., Seto, K. C., Bai, X., Blanco, H., Gurney, K., Kılkış, Ş., Lucon, O., Murakami, J., Pan, J., Sharifi, A., & Yamagata, Y. (2022). Urban Systems and Other Settlements. In P. R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, & J. Malley (Eds.), *Climate Change 2022: Mitigation of Climate Change: Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press.

Meadows, D. H. (2008). *Thinking in Systems: A Primer*. Chelsea Green Publishing.

Mengelkamp, E., Gärttner, J., Rock, K., Kessler, S., Orsini, L., & Weinhardt, C. (2018). Designing microgrid energy markets. A case study: The Brooklyn Microgrid. *Applied Energy*, *210*(6), 870–880. https://doi.org/10.1016/j.apenergy.2017.06.054

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

Ortiz, W., Dienst, C., & Terrapon-Pfaff, J. (2012). Introducing Modern Energy Services into Developing Countries: The Role of Local Community Socio-Economic Structures. *Sustainability*, *4*(3), 341–358. https://doi.org/10.3390/su4030341

Pieńkowski, D., & Zbaraszewski, W. (2019). Sustainable Energy Autarky and the Evolution of German Bioenergy Villages. *Sustainability*, *11*(18), 4996. https://doi.org/10.3390/su11184996

Rassa, A., van Leeuwen, C., Spaans, R., & Kok, K. (2019). Developing Local Energy Markets: A Holistic System Approach. *IEEE Power and Energy Magazine*, *17*(5), 59–70. https://doi.org/10.1109/MPE.2019.2921743

Reynolds, M., & Holwell, S. (2010). Introducing Systems Approaches. In M. Reynolds & S. Holwell (Eds.), *Systems Approaches to Managing Change: A Practical Guide* (pp. 1–23). Springer.

Schmidt, J., Schönhart, M., Biberacher, M., Guggenberger, T., Hausl, S., Kalt, G., Leduc, S., Schardinger, I., & Schmid, E. (2012). Regional energy autarky: Potentials, costs and consequences for an Austrian region. *Energy Policy*, *47*, 211–221. https://doi.org/10.1016/j.enpol.2012.04.059

Schot, J., & Geels, F. W. (2008). Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. *Technology Analysis & Strategic Management*, *20*(5), 537–554. https://doi.org/10.1080/09537320802292651

Seidl, R., Wirth, T. von, & Krütli, P. (2019). Social acceptance of distributed energy systems in Swiss, German, and Austrian energy transitions. *Energy Research & Social Science*, *54*(4), 117–128. https://doi.org/10.1016/j.erss.2019.04.006

Seyfang, G., & Smith, A. (2007). Grassroots innovations for sustainable development: Towards a new research and policy agenda. *Environmental Politics*, *16*(4), 584–603. https://doi.org/10.1080/09644010701419121

Sovacool, B. K. (2009). The cultural barriers to renewable energy and energy efficiency in the United States. *Technology in Society*, *31*(4), 365–373. https://doi.org/10.1016/j.techsoc.2009.10.009

Späth, P. (2012). Understanding the Social Dynamics of Energy Regions—The Importance of Discourse Analysis. *Sustainability*, *4*(6), 1256–1273. https://doi.org/10.3390/su4061256

Szejnwald Brown, H., & Vergragt, P. J. (2012). Grassroots innovations and socio-technical system change: Energy retrofitting of the residential housing stock. In G. Marletto (Ed.), *Creating a Sustainable Economy: An institutional and evolutionary approach to environmental policy* (pp. 154–176). Routledge.

Trutnevyte, E., Stauffacher, M., Schlegel, M., & Scholz, R. W. (2012). Context-specific energy strategies: Coupling energy system visions with feasible implementation scenarios. *Environmental Science & Technology*, *46*(17), 9240–9248. https://doi.org/10.1021/es301249p

van de Graaf, T., & Sovacool, B. K. (2020). *Global energy politics*. Polity.

Verbong, G., & Geels, F. W. (2012). Future electricity systems: visions, scenarios and transition pathways. In G. Verbong & D. Loorbach (Eds.), *Governing the Energy Transition: Reality, Illusion or Necessity?* (pp. 203–219). Routledge.

Vereniging Vriendenerf. (2012). *Vriendenerf: Een duurzaam CPO-project voor vijftigplussers.Werkdocument 'Visie en ambitie'*. https://www.vriendenerf.nl/gallery/vriendenerf_visie_v1.0.pdf

Weinand, J. M., Ried, S., Kleinebrahm, M., McKenna, R., & Fichtner, W. (2022). Identification of Potential Off-Grid Municipalities With 100% Renewable Energy Supply for Future Design of Power Grids. *IEEE Transactions on Power Systems*, *37*(4), 3321–3330. https://doi.org/10.1109/TPWRS.2020.3033747

Wirth, T. von, Gislason, L., & Seidl, R. (2018). Distributed energy systems on a neighborhood scale: Reviewing drivers of and barriers to social acceptance. *Renewable and Sustainable Energy Reviews*, *82*, 2618–2628. https://doi.org/10.1016/j.rser.2017.09.086

Woch, F., Hernik, J., Wiklina, U., & Tolak, M. (2014). Energy Autarky of Rural Municipality Created on the Basis of Renewable Energy Resources. *Polish Journal of Environmental Studies*, *23*(4), 1441–1444.

Yun, S., & Lee, J. (2015). Advancing societal readiness toward renewable energy system adoption with a socio-technical perspective. *Technological Forecasting and Social Change*, *95*(2), 170–181. https://doi.org/10.1016/j.techfore.2015.01.016