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1 Executive Summary

The overall objective of this deliverable is to introduce an analytical framework for the ex-post evaluation of the demonstration sites to develop socio-economic solutions and tools for affecting the local energy system and collective action in communities. To be able to systematically evaluate the socio-economic change and effects in the local energy systems and in the collective action in the demonstrator sites, we need explicit evaluation criteria and a valid evaluation research design and research choices. Therefore, this deliverable formulates an analytical framework that defines the evaluation concepts, criteria, and basic steps of the evaluation.

In the analytical framework we describe six different evaluation elements of change in the local energy systems.

1. Describing system changes, in term of system effects and system characteristics.
2. Goal achievement on the SUSTENANCE project goals for the local energy systems in the demo sites, formulated as carbon-neutrality, decentralization, sustainability, efficiency and energy integration.
3. Goal achievement on the local energy system goals from the actors in the cases.
4. Describing the autarkic system state for different autarkic dimensions
5. Describing factors influencing the innovations and innovation management in the demo sites
6. Assessment of the relation between the innovations in the demo sites and the system changes.

The evaluation elements help answer two central questions:
1) In how far do social-economic system characteristics influence the possibilities of technical innovations to change the local energy system in the demonstrators towards more autarkic carbon-neutral energy communities?
2) In how far do (social) innovations themselves change the local energy system in the demonstrators towards more autarkic carbon-neutral energy communities?

Section 2 discusses the objective of this deliverable. Section 3 discusses system change as a transition towards carbon-neural local energy systems and introduces our demo sites. In section 4 we discuss the evaluation of system change, which we divide in an evaluation of the system state based on a so-called goal-free and effect overview and a process evaluation of the innovations that are initiated to change the system. Section 5 introduces the criteria to assess system change being the project and demo goals and the characteristics of a more autarkic local energy system. In section 6 we discuss the process evaluation of the innovations in the demo sites on the basis of concepts from strategic-niche management theory. Section 7 addresses the evaluation design and data collection. Finally, section 8 introduces the basic evaluation elements of our framework based on all previous sections.

2 Introduction

The key focus of the SUSTENANCE project is to build carbon-neutral energy communities by establishing local, sustainable and efficient integrated energy systems. The main objective of SUSTENANCE is to develop and demonstrate smart techno-socio-economic and eco-friendly solutions and tools for effecting multi-energy systems and collective action in communities. This is to maximize the local use of renewable energy and enable energy efficiency. In the previous deliverables D3.1 and D3.2 of the SUSTENANCE Work package 3 we placed the local utilization of renewable energy resources within the concept of autarky. Working towards energy autarky is one of the important focus areas of the SUSTENANCE project and an important driver for collective action in communities.

The overall objective of this deliverable is to introduce an analytical framework for the ex-post evaluation of the demonstration sites to develop socio-economic solutions and tools for affecting the local energy system and collective action in communities. To be able to systematically evaluate the socio-economic change and effects in the local energy systems and in the collective action in the demonstrator sites, we need explicit evaluation criteria and a valid evaluation research design and research choices. Therefore, this deliverable formulates an analytical framework that defines the evaluation concepts, criteria, and basic steps of the evaluation. It is not a detailed guideline for the local energy system evaluation in the individual demonstrator site, but instead, it discusses the common concepts, steps, and socio-economic and autarky evaluation criteria.

We introduce here a framework to evaluate the build carbon-neutral energy communities on their progress towards a more autarkic local energy system. A more autarkic local energy system has both a social-regulatory dimension and a physical-technical dimension as was explained in deliverables D3.1 and D 3.2 of the SUSTENANCE project Work package 3. The purpose of the framework to determine the socio-economic local energy system changes towards carbon-neutrality and sustainability and relate these changes to the socio-economic interventions (social innovation). The main goal is sketch an evaluation framework to help understand how the socio-economic aspects and characteristics of the established local, sustainable, and efficient integrated energy systems in the demo sites contribute to carbon-neutral energy communities.

The interventions in the local energy system in the demo sites are smart techno-socio-economic and eco-friendly solutions and tools for effecting multi-energy systems and collective actions in communities. These interventions are innovations in the system. The SUSTENANCE project Work package 3 is about the socio-economic changes. Apart from how social innovations themselves, like establishing a new local energy citizens community initiative, contribute to the carbon-neutral energy communities, social-economic factors also influence technical innovations changing the local energy system in the demonstrators.

In this deliverable, we introduce a framework for ex-post evaluation to determine the socio-economic local energy system changes and attribute these changes to the socio-economic interventions (social innovation) and to understand the attribution of social factors to the technical system change.
The analytic framework provides the key social, economic, and regulatory variables to help answer two central questions:

1) In how far do social-economic system characteristics influence the possibilities of technical innovations to change the local energy system in the demonstrators towards more autarkic carbon-neutral energy communities?
2) In how far do (social) innovations themselves change the local energy system in the demonstrators towards more autarkic carbon-neutral energy communities?

In the first stage of WP3 we evaluated the challenges that obstructs the creation and operation of carbon-neutral energy communities, particular from an autarchic system perspective. It includes social, regulatory and economic factors and conditions that influence the demonstration activities and sites in the different regions and countries. We collected first field data, previous research, interviews or focus group meeting with the main stakeholders and site visits to describe the starting situation in the demo sites. We reported about this in deliverables 3.1 and 3.2 under SUSTENANCE work package 3. In the second stage**,** a first comprehensive analytic framework and criteria for efficient and sustainable organizational configuration for more autarkic energy communities is established. This deliverable 3.3 is the start of this second stage.

The purpose of the evaluation of the local energy system is to assess the progress toward a carbon-neutral energy community in the demonstrator sites at the end of the project. Therefore, it is focused on the socio-economic effects of the established system as well as the socio-economic processes and substance of the established local, sustainable and efficient integrated energy systems. We follow a mixed-method approach based on the idea of a systemic evaluation, bringing different evaluation components in terms of criteria and methods together in one system.

3 System change toward carbon-neutral energy communities

Going from a largely fossil-fuel-based energy system to local, sustainable, and efficient integrated energy systems to build carbon-neutral energy communities is a system change. In Work package 3 we therefore apply a *systems approach* to the local energy transition toward higher self-sufficiency or autarky. Whereby we consider the energy system as a *socio-technical system*, i.e., a system that includes both technical components, such as different pieces of energy infrastructure or equipment, and social-economic 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 analyzed in tandem rather than separately.
To study the transition from a largely fossil-fuel-based energy system to a local, sustainable, and efficient integrated energy system we use concepts from the so-called transition literature to assess the progress toward carbon-neutral energy communities. In WP3 we look at socio-economic system change in the demonstrator site and the changed level of autarky.

"*A transition is a gradual process of societal change in which society or an important subsystem of society structurally changes*" (Rotmans et al. 2000, p. 19). A transition is the result of
the interplay of developments that sustain and reinforce each other. Transitions to a different energy system are not caused by single variables or events like an energy price change, a new energy policy act or a new energy technology, but are the result of developments in various domains which sustain each other: technology, economy, institutions, behaviour, culture, ecology, and images/paradigms (Rotmans et al. 2000, p. 19p. 20). The process of system change in the demo sites will not be a linear transition. Slow change can be followed by rapid change. Technical and social innovations might reinforce each other, and lead to rapid change. While if the local energy system reaches a stabilisation stage change might be much more slower.

Although transitions take place over a long period of up to 30-40 years, and the time span of the SUSTENANCE project is limited, the concepts from transition literature are still valuable. The demo sites present cases that already are in different phases of transition towards a more autarkic local, sustainable, and efficient integrated energy system (see hereafter).
The transition phases or stages are categorised in four stages with different characteristics (Rotmans, et al 2001). This is illustrated in figure 1 where social development is set off against the time dimension.

- In the predevelopment phase there is very little visible change on the societal level but there is a lot of experimentation
- In the take-off phase the process of change gets under way and the state of the system begins to shift.
- In the breakthrough phase structural changes take place in a visible way through an accumulation of socio-cultural, economic, ecological and institutional changes that react to each other; during this phase, there are collective learning processes, diffusion and embedding processes.
- In the stabilisation phase the speed of societal change decreases and a new dynamic equilibrium is reached.

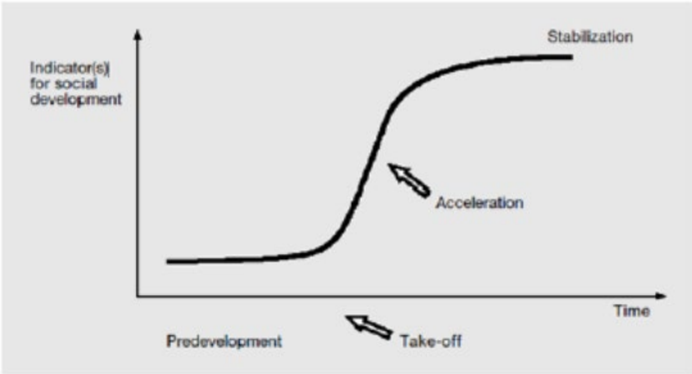


Figure 1. Transition phases. From "More Evolution than Revolution: Transition Management in Public Policy," by J. Rotmans, R. Kemp, and M. van Asselt, 2001, Foresight, 3(1), p. 17

We shortly sketch here the demo sites in our project.

Denmark

Voerladegård is a village of ca. 550 inhabitants in the municipality of Skanderborg in the Central Denmark (Midtjylland) Region. The demo site includes 20 houses within the village and the surrounding area, which will be outfitted 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.

India

Barubeda village

Barubeda is a remote agricultural village in Jharkand state with around 57 houses. 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 infrastructure 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.

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 40 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.

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.

Netherlands

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.

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 users and the energy system, e.g., via innovative apps or business models

Poland

Mickiewicza Street

The demo site in Poland is 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.

The demo sites in the four countries present cases that already are in different phases of transition towards a more autarkic local, sustainable, and efficient integrated energy system. All demonstrator sites have some smart techno-socio-economic and eco-friendly solutions and tools for effecting multi-energy systems and collective action in communities in place. The Vriendenerf case also already has a clear energy community organisation in place. In the Danish cases, the Polish case and the Indian village case there are already organisational arrangements in place, like house owners or tenants organisations and village councils, that could lead to local energy communities. All demo sites are either in the predevelopment phase or will be soon, because there is a lot of experimentation planned. In those demo sites that are starting up there might still be little visible change on the societal level, but there is a lot of experimentation. The Dutch cases are in the take-off phase, where the process of change is already under way and the state of the system begins to shift. But further structural changes like an exchange of energy within the community, have still to become more visible in these demos. There is not yet a breakthrough phase and an accumulation of socio-cultural, economic, ecological and institutional changes that react to each other.

4 Evaluating local energy system change towards carbon-neutral communities and autarky in the demonstrator sites

We are using a systems lens to see changes in our demo sites and their energy communities. The key focus of the SUSTENANCE project is to build carbon-neutral energy communities by establishing local, sustainable and efficient integrated energy systems. More sustainability of the system builds on renewables that do not necessarily have to be produced locally. However, systems that build on the integration of multi-carrier energy systems in the local energy system need to be more decentral. Technically, the implementation of energy autarky rests on increasing energy efficiency, realizing the potential of renewable energy resources and decentralizing the energy system.

Citizens organized in local energy communities, particularly REScoops (Renewable Energy Sources cooperatives), also lead to a more 'decentral system based on local renewable production (Coenen and Hoppe, 2021). REScoops are energy cooperatives, a business model where citizens jointly own and democratically control an enterprise that works on renewable energy or energy efficiency projects. REScoops are a particular type of citizen or renewable energy communities, which are legal forms under EU directives (Coenen and Hoppe 2021). The EU's revised Renewable Energy Directive (2018/2001) and Internal Electricity Market Directive (2019/944) have provided a framework for respectively renewable energy communities and citizen energy communities. REScoops mostly operate in local energy production. Direct citizen participation in for instance offshore wind energy is limited other than trough dividend-based investment schemes. A specific aspect of energy communities based on the Renewable Energy Directive is that members of these local energy communities are place bound. Article 2 paragraph 16 of the recast Renewable Energy Directive) explicitly talks about shareholders or members that are located in the proximity of the renewable energy projects that are owned and developed by that legal entity. Prosumers are an important part of the local energy system. Inherent in the word 'prosumers is that they are energy citizens who produce at the local level.

The evaluation framework is to assess if the energy systems in the demo sites evolved towards more carbon-neutral, local, sustainable and efficient integrated energy systems. Autarky is the characteristic of self-sufficiency applied to local communities and their local energy systems. The evaluation framework we present here is a basis to see in how far a higher stage of autarky is reached in the local energy systems. Reaching a certain state of the local energy system is based on a set of variables that describes the behavior of the system at a particular time. The state of a system is defined by ascribing values to these variables.

We can distinguish two different evaluation objects within our evaluation approach. By evaluation object, we mean what specific projects, measures, and organizational aspects we take into consideration in the evaluation. The first object of the evaluation is on the level of the socio-technical local energy systems being our demo sites. This evaluation part is focused on the transition of the demo sites' local energy systems from a largely fossil-fuel-based energy system to local, sustainable, and efficient integrated energy systems to build carbon-neutral energy communities and support the overall network balancing, by providing ancillary services. The second object is the evaluation of the social and technical innovations that take place within the socio-technical local energy system. These innovations are interventions in the system to bring about system change.

Assessment of a local energy system is the confrontation of observation with a certain standard. Therefore, we need criteria or standards before we can evaluate. Types of evaluation are related to certain subject matters. The subject matters of evaluation of a local energy system transition may include the (changed) substance of the system, intervention processes in the system, and effects of the transition. The evaluation of a change system substance is associated with both the intervention process and transition effect evaluation. A process evaluation is the assessment of the interventions in the local energy system, which are the technical and social innovations, based on certain criteria. An evaluation of the effects of interventions in the system is a goal-achievement evaluation. The purpose of the evaluation of the local energy system is to establish the progress in socio-economic system change in the demonstrator sites at the end of the project.

Assessing energy systems on carbon-neutrality, decentralization, sustainability, efficiency and energy integration is not a classical goal achievement evaluation. Effect evaluation is concerned with investigating effects. Goal achievement is to what degree the interventions in the local energy system have achieved the goals set. One can distinguish between various types of effects in the local energy system. If the system interventions achieve the effects envisioned by those who conduct it, then we use the term envisioned effects. Changes in the local energy system can however also concern effects that were not envisioned, the so-called side effects. The degree to which the envisioned effects are achieved is called goal achievement. In that sense, goal achievement is about the selection of the envisioned effects in the goal. Here we think not so much in terms of specific goals concerning the overall local system and particular envisioned effects we want to reach, but we will be studying a broader set of effects that might not be related to a specific goal. So, it is more system effect research than goal achievement research.

Further, the possibility of a goal achievement evaluation depends on the formulation of the aims in relation to goal achievement. The measurability of a goal depends on whether it indicates a direction, can be quantified, and is time-limited. However, as seen in chapter 3, the demo sites do not have clear goals concerning the overall local energy system change but more technical goals and changes in the infrastructures (heat and EV charging). The SUSTENANCE project has goals concerning the demo sites, carbon-neutrality, decentralization, sustainability, efficiency and energy integration but they have only a direction. As we have seen in chapter 3 the demo sites themselves also have goals, but no always clear pre-determined goals at this moment.

Goal-free evaluation is an evaluation in which the evaluator conducts the evaluation without particular knowledge of or reference to stated or predetermined goals and objectives (Scriven, 1991). Particularly for the evaluation of the change of the demo sites towards autarky we will use the concept of a goal-free evaluation. Several arguments are given in the literature for a goal-free evaluation. One argument is that we do not know the ‘true’ goals. Even if goals are expressed by the initiators of the system change are these really the goals the initiators are striving for, or are they just formulated for political or organizational reasons? And if, does it mean these goals have no meaning for evaluation? In evaluation research, one argument is that even if the goals “on paper” are not the true goals, they might still be the goals approved by a democratic institution like a parliament or local council. The goals are the political legitimization of the tax money spent, so the question if goals are reached is important.

Another argument for the use of goal-free evaluation is that goal achievement evaluation would lead to a tunnel vision of the effects to take into consideration. But this is the actual idea of a goal achievement evaluation. Of all effects somehow related or relevant to the intervention under study a goals achievement evaluation focuses on a selection of effects namely the effects specified in the goals. These are the effects the initiator of the interventions wants to reach.

Here we use the concept of goal-free evaluation because we have a still need more clearly stated overall goals in a local energy system, and want to avoid a tunnel vision. A goal achievement evaluation and a broad effect evaluation are two different approaches. If a goal-free evaluator observes and measures all actual effects, intended or unintended, without reference to any of the goals to be achieved it gives a broad overview of effects, but it is not an evaluation because there is no standard or criteria to assess the effects against. The risk then is that the “official goals” are replaced with the evaluator’s (interpretation) of the goals or his preference. In our evaluation of system change, we will focus on finding out what is actually happening in the local energy system. We do not neglect the intentions of the local actors with the system change and do not intentionally neglect goals. In the process of assessing the system changes in the demo sites, we will work with the local actors to get clarity about their goals. During the process, the broad overview of effects will be confronted with these goals. If the program is achieving its stated goals, then these achievements are measured on basis of the effects found. Although the effects stated in the goals are a selection of all effects we study. However, if these stated goals are not achieved these are not irrelevant. As we have argued before these goals are the legitimacy to spend money ad efforts on trying to reach these goals.

None of our demo sites has explicit goals in the sense that they explicitly state they want to be more autarkic, but implicit they have goals that if they are fulfilled would lead to more autarky. Goals formulated for a local energy system as ‘not using the grid as a big battery’, ‘striving for sustainable self-sufficiency’, and ‘trying to use as much locally produced renewables’ means striving towards more autarky. To be able to compare the state of autarky of the local energy systems in the demo sites the starting point is not the local goals per demo, but the state of the autarkic characteristics of the local energy system. The outcome of the system change in the local energy systems in the demo sites is measured against this potential status of autarky. We introduced dimensions for autarky in deliverables 3.1 and 3.2. Systematically looking at the broad overview of effects gives us a ‘state of the system’ report. If the system due to system change is moving in a certain direction, this can be based on qualitative and quantitative indicators. Describing the movement does not have to be a normative assessment, as long as we do not introduce criteria. For autarky we describe the system change but do not weigh the movement of the system on the different dimensions. But we will introduce in the next section indicators for the direction of the system change. We will also discuss goals, the project goals and demo sites goals, as criteria. Goals are a selection of all possible effects based on the effects we want to achieve with these goals. We are looking for a broader perspective were we supplement systematically looking at the broad overview of effects as a ‘state of the system’ report with a more goal-based evaluation

5 Operationalizing and measuring local energy system change

5.1 Project goals and system state of autarky

In this section we discuss how we measure change of the local energy systems in the demo sites towards more carbon-neutral, local, sustainable and efficient integrated energy systems. We also discuss how we measure if a higher stage of autarky is reached in the local energy systems. Reaching a certain state of the local energy system is based on a set of variables that will describe the behavior of the system at a particular time. The state of a system is defined by ascribing values to these variables.

As we have seen **t**echnically, the implementation of energy autarky rests on increasing energy efficiency, realizing the potential of renewable energy resources and decentralizing the energy system. Autarky is not just about technical system changes. It also requires administrations and civil society actors to initiate projects at the local level, ensure their acceptance and support by the population, and implement the project in collaboration with relevant actors. As concluded in deliverable 3.1 autarky refers to “economic independence or self-sufficiency”. Where in contrast, the term autonomy refers to “freedom from external control or influence”. Energy autarky means that a geographical area or a local energy system relies on its own resources to satisfy its needs as much as possible. Full autarky is unlikely to be achieved. An autarkic energy community as we define/perceive it in SUSTENANCE is not necessarily striving for self-governance (autonomy) but rather relies on its interrelationships with the surrounding governance system to potentially achieve more autarky. The system surrounding the local energy system has also to give the possibility for more autarky. For instance, national government should leave more policy decisions to the local level and/or regulation should open for the local system with sandbox or experiment regulation that allow for self-sufficiency. Again, it is not a goal that all small communities should be self-sufficient, but to be able to understand the effects of more autarky.

As we discussed in the previous section, the local energy systems in the demo sites do not have have explicit goals of becoming more autarkic. Neither we want to make the point here that the local communities should strive for as much autarky as possible, since this is maybe not the most optimal solution. We want to understand the level of autarky and understand its effects. Some goals of the local energy systems might address the carbon-neutrality, local dimension, sustainability, efficiency and integration of the systems. We will first on the basis of the principle of a goal free evaluation sketch a broad overview of system change effects and changes in system characteristics. This ‘state of the system’ overview will be confronted with explicit and implicit goals of initiators of system interventions and other stakeholders within the local energy system in the demo sites. For both the broad overview of system change effects and changes in system characteristics and the confrontation of the effects and changes with explicit and implicit goals we need some operationalisation of criteria and introduction of indicators. This is a start of a process of gaining progressive insights in the system changes and system effects and their relation with the goals we will find in the demo sites. These goals are a selection of these system effects and system changes defined by the initiators of intervention and other stakeholders. The goals define what effects and system changes the initiators of interventions want to reach.

The project goals for the local energy systems in the demo sites moving towards more carbon-neutral, local, sustainable and efficient integrated energy systems. Although all these elements are related with autarky, autarky is not a goal in itself. The goal of a local communities being more autarky, does not necessarily make the overall system more sustainable, since we need the flexibility from the local communities to support the overall system, if all smaller communities become autarky, the overall system will not work. Therefore, we measure system change in other matters depending on the demonstration site goals as well.

To be able to compare the state of autarky of the local energy systems in the demo sites the starting point is not the local autarkic goals per demo, but the state of the autarkic characteristics of the local energy system. The outcome of the system change in the local energy systems in terms of autarky in the demo sites is measured against this potential status of autarky.

5.2 Evaluation based on the SUSTENANCE project goals

The SUSTENANCE project has several goals that the local energy systems in the demo sites are striving for; carbon-neutrality, decentralization, sustainability, efficiency and energy integration. These goals might not be formulated by the actors in the demo sites. We give a first sketch of indicators for these project goals. Per demo site and in collaboration with the demo site actors these indicators have to be further elaborated upon in the demo sites work packages 4,5,6 and 7. We also link this first sketch of indicators with the indicators for autarky as we discuss in the next section. Logically a higher stage of autarky reached in the local energy systems is linked with the project goals for the demo sites as we explained in section 4.

Carbon-neutrality is about the CO2 emissions of the local energy system. Our perspective is the carbon footprint of the whole system. Use of renewable energy is one indicator, but this does not have to be locally produced renewable energy. Other indicators concern the electrification of the system, like the replacement of fossil fuel transport by EV and fossil fuel heating, like heat pumps, sustainable district heating or biogas. An autarkic system does not have to be a carbon neutral. but carbon-neutrality is more important in our project than autarky.

Local is the opposite of centralised energy production, particular for electricity production. The electricity generated by centralized generation is distributed through the electric power grid to multiple end-users. Also centralised produced energy can be renewable like from off-shore wind, hydropower or solar photo voltaic. A local energy system is always part of a larger energy system unless it is a fully autarkic system. We interpret local here as the amount of renewable energy locally produced, although there might also be local fossil fuel generated electricity. We present some indicators under the characteristic; local renewable energy sources. Local in a local socio-technical system can also be seen as a larger involvement or decision-making power of local actors. We present some indicators under the autarky characteristics; social organization and self-governance.

Sustainability has three dimensions: social, environmental and economic. Sustainability is measured by assessing performance within the social, environmental, and economic dimension, balancing the dimensions. To measure the degree of sustainability of a local energy system we can choose from a large amount of methods and indicators. Our choices are based on the goals for local energy system processes. For the environmental dimension we therefore refer to the criterium of carbon-neutrality. For the economic dimension we refer to investments in renewable energy production and cost-efficiency of the system. The social dimension has many dimensions but related to community goals for local energy systems we refer to local communities democratic principles and level of energy self-governance.

Multi-Energy system integration refers to the planning and operation of the energy system as a whole - across multiple energy carriers (e.g. electricity, gas, heat), infrastructures, and consumption sectors (industry, buildings, transport) - by more strongly linking them with the objectives of decarbonisation, energy efficiency, affordability and reliability of the energy system (Council of the EU, 2019). It includes three complementary and mutually reinforcing concepts (Council of the EU, 2019):

- A more circular energy system, with efficiency at its core;
- A greater direct electrification of end-use sectors;
- The use of renewable and low-carbon fuels, including hydrogen, for end-use applications where direct heating or electrification are not feasible, not efficient or have higher costs.

5.3 Indicators for a higher stage of autarky of the local energy systems.

In deliverables 3.1 and 3.2 we followed a three-step approach to develop a typology of more autarkic local energy systems. In the first step we defined nine key physical-technical and social-regulatory dimensions (axes) that capture the various socio-technical configurations that lead to various degrees of energy autarky. We also defined four non-energy sectors that have a significant interrelationship with the local renewable energy systems. In the second step we develop a method to represent and compare the position of the SUSTENANCE demonstrators in the aforementioned dimensions, thus identifying preliminary clusters as types of autarkic energy communities in the SUSTENANCE sample of communities. In the third step we proceeded with a dimensionality reduction where the complete set of dimensions is reduced to two axis, one physical-technical and one social-regulatory, which makes up the final taxonomy of autarkic communities in SUSTENANCE as well as the final description and implications of the identified types

We recapture and summarize here the nine characteristics on the two dimensions in table 1 and 2.

Table 1 Physical-technical dimension

Characteristic	Description	Autarkic system state strived for
Technological dependence	Degree of grid integration of the community. This ranges from full integration all the way to no integration / island status.	The system is technologically able to share and store energy within the system, and does not need to (fully) rely on the larger grid for these services
Local renewable energy sources	Mix of local sources of renewable energy (e.g., wind, solar, geothermal) and the total capacity to provide local renewable energy.	100% of local demand can be covered with local RES

Settlement characteristics	Scale, and density, and connectivity as key urban morphological parameters, as important aspect of the complexity of energy demand related to the dependency of land uses and built-up form.	Settlement is self-sufficient in supplying for residents' demand as well as recovering/recycling/disposing own waste/emissions.
Building characteristics	Architectural and engineering characteristics of individual residential (and commercial, industrial, and public) structures, determining (in combination with the complexity of energy demand) the various demands that the community has for their local autarkic energy system.	Fully passive heating and cooling, meeting thermal comfort needs solely on the diurnal energy balance through natural means.
Complexity of energy uses	Complexity of energy demand, to understand whether the community looks at energy autarky for basic needs only or for the full spectrum of uses (including dependencies of food, water, waste, and mobility).	High synergies between different energy use

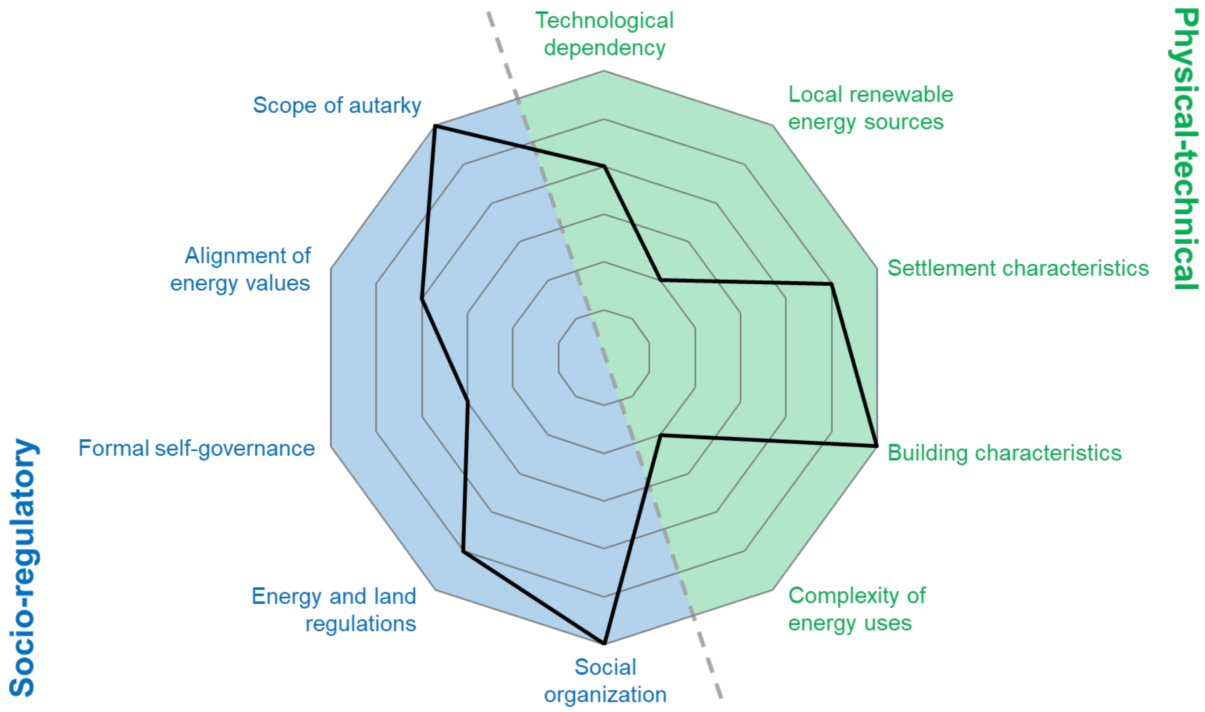
Table 2 Social-regulatory dimension

Characteristic	**Description**	**Ideal state for autarkic system**
Social organization	Diversity, density and complexity of informal social networks (such as clubs and organizations) within the autarkic community, ranging from absence of such forms of social organization all the way to an elaborate structure of multiple overlapping networks.	Elaborated structure of overlapping social networks and active citizenry
Energy and land regulations	Legislative and regulatory context in which autarkic communities are realized and developed (e.g., energy market regulations, system operation regulations).	High degree of freedom to experiment and implement local solutions independently
Sophistication of formal self-governance	Type, structure, and "weight" of governance system in place, ranging from a sophisticated set of rules to a completely ad-hoc set of practices.	A high level of local community autonomy, to govern on its own initiative, the local (energy) affairs of its community. Maximum subsidiarity
Alignment of energy values	This dimension pertains to the fact that there is always an underlying motivation and value being generated by a local community approach to sustainability and resilience. This for instance can be purely instrumental such as affordability or broader such as environmental	High degree of agreement / alignment of values related to autarkic energy system within the community

	preservation or procedural/distributive fairness. We aim here to capture the diversity and synchronization of these.	
Envisioned scope of autarky	Although autarky is not a goal in itself, a community can have collective plans on moving towards an autarkic system in terms of scope (also other aspects than energy), aim (100% autarky) and time (daily seasonal or yearly net zero balance).	Autarky in terms of self-sufficiency in all services like food provision, economic system, and mobility to reduce any influence from outside on the functioning of the community.

On the basis of guiding descriptive questions in deliverable 3.1 we described the dimensions for the demo sites at the start of the demo sites. Here we will take the ideal state of autarky or the status to strive for to formulate first indicators to measure the change on the dimensions. These indicators need to be further developed with the actors the demo sites. The measurement of the indicators just gives a direction of the individual dimensions, there is no weighing between the dimensions indicators and the status of the sperate dimensions cannot simply be added to one autarky status.

Fig 1 Example of scores on autarky dimensions



5.4 Physical-technical dimension

5.4.1 Technological dependence

The first physical-technical dimension is how is the local energy system in the demo site is integrated into larger energy grids. A more autarkic system state would be that the system is technologically able to share and store energy within the system, and does not need to (fully) rely on the larger grid for these services. This dependency on the larger grid in ascending degree of dependency from the highest to the lowest degree of dependency;

- one-way consuming, only receiving energy from the larger grid;
- one-way feeding, only feeding energy to the larger grid;
- reciprocal (two-way, receiving energy from the larger grid and feeding locally produced energy into the larger grid;
- partial network or distributed system (micro-grid or subnet for internal distribution within the project area, connected to the larger grid);
- (hard) islanding (project area has its own energy supply, which is distributed and used within the project area only).

If there is a technical or voluntary restriction on receiving energy from the grid we could think in terms of soft islanding. A real energy island will not have only a specific technical architecture but also a matching organisational design.

Energy islanding is not only the connection with larger grid but also connection within the grid and individual energy consumers (such as classical connection with individual meters; collective connection with autonomous internal distribution mechanisms; prosumers feeding electricity back into the grid; supplying biogas by farmers; recycling waste-heat from companies; etc.)

5.4.2 Availability of local renewable energy sources

The second physical-technical dimension is in how the local energy system in the demo site is self-sufficient due to the availability of enough local renewable energy sources. A more autarkic system state would be an autarkic system state where 100% of the local demand can be covered with local RES. In table 3 we introduce some indicators for the move from the current installed capacity for energy production from RES, compared to the energy demand towards a more autarkic state.

Table 3 *Technical indicator community self-sufficiency*

Technical indicator community self-sufficiency	**Measurement unit**
Increased locally produced RES-electricity	kWh/year; %
Increased locally produced RES-heat	kWh/year; %
Reduced fossil fuel consumption in the electricity area	kWh/year; %
Reduced fossil fuel consumption in heat sector	kWh/year; %
Provision of uninterruptible, cost-efficient and reliable electricity supply, supplied by variable renewable sources,	
Flexibility possibilities - movement of electricity from high to low load period	kWh/year; %

Exchange of households from coal or gas to locally produced electricity	total number
Exchange of fossil fuel cars with electric cars	total number
Increase of EV charging points in the area	%
Growth in battery capacity installed	%

Availability of local resources is not only about the installed and available capacity but also about the changes in the energy supply active in the demo site.

5.4.3 Settlement characteristics

The third physical-technical dimension is that the settlement characteristics in the local energy system in the demo site realise as much self-sufficient supply for residents' demand in the system as well as recovering, recycling and disposing the local system's own waste and emissions. A more autarkic system state would be a system where waste and emissions are minimized, it does not necessarily have to be in the form of a closed system, it is merely that the citizen in the community is looking into the overall sustainability, and have the possibility for recycling as emissions reduction as much as possible. This depends on several factors like:

- location of the project site: urban, sub/peri-urban, rural or remote;
- the local system dimensions in hectares;
- type of residential buildings: apartments, townhouses / row houses, detached or semi-detached houses (free-standing), huts / sheds;
- types of other buildings in the project area (e.g., commercial, industrial or public buildings);
- main land uses in the project area and the surrounding areas:
- building density in the project area, compared to the regional average.
- Connections to the outside system (regional) for waste handling

It is not obvious which change in the settlement characteristics in the demo sites would lead to a higher stage of autarky and what it should be in the end. It is not about the changing characteristics, but if the change of characteristics contribute to a local energy system where waste and emissions are minimized.

5.4.4 Building characteristics

Building characteristics are the specific architectural and engineering characteristics of the individual buildings. The fourth physical-technical dimension is how the building characteristics in the local energy system in the demo site make the buildings more self-sufficient and carbon neutral in their supply for residents' demand of heath and cooling.

Measuring changes in the building characteristics towards more self-sufficiency in the demo sites can be based on indicators like:

- higher environmental or energy standards applied in the design and construction or renovation of buildings (or in more buildings);
- more insulated houses, more houses with a higher level of insulation, or more houses with specific characteristics like green roofs;
- more houses with a different ways of delivering basic services to the buildings that contribute to energy efficiency.

5.4.5 Complexity of energy uses

The fifth physical-technical dimension is in how far other aspects and forms of energy uses, than fulfilling the basic (households) energy needs with production and demand in a more autarkic way, are taken in consideration in the local energy system in the demo site. A more autarkic system state would be a high synergy between different energy use. So the community looks at energy autarky for the full spectrum of uses (including dependencies of food, water, waste, and mobility). With electrification the use of renewable energy, particular renewable electricity, changes. A higher status of autarky would be:
- more synergies with other sectors, such as mobility or solid waste, to reduce energy demand;
- more flexibility and energy demand measures aiming at end-consumers;
- more planning, control and operation of the energy system as a whole - across multiple energy carriers (e.g. electricity, gas, heat), infrastructures, and consumption sectors (industry, buildings, transport).

5.5 Social-regulatory dimension

In case of a geographical area (e.g. isolated villages, small cities, urban districts, rural areas) with weak or non-existing grid connections, not only a specific technological configuration of a local energy system is needed. Given the availability of local renewable resources, the specificity of the demand and supply of the more autarkic local energy networks we need an organisational configuration that aligns with such a renewable based energy system. Compared with a decentralised local renewable energy system that functions within a largely centralised, mostly fossil fuels energy based system, a more autarkic system has consequences for the position of the (local) stakeholders on the energy market, the need for exemptions from general regulation, the way participation in energy system decisions is organised, ownership, and user acceptability. To optimise a local more autarkic energy system and particular the flexibility options, there is more need for certain specific technological characteristics, like storage and demand control. The acceptance of these new technologies and behavioural changes in energy demand are crucial for the flexibility options in the more autarkic energy system. This flexibility options asks for a strong citizen engagement component that leads to new business models, split incentives and an organisational model with ownership and participation in decision-making, that will contribute to behavioural change, user acceptability and social norm setting in the energy community.
The organisational set-up of such an energy community has as a key element as a cooperative or another type of collective actions from the community members. Therefore, the demonstration sites are as much about social innovations as about technological innovations.

5.5.1 Social organization

The first social-regulatory dimension is the diversity, density and complexity of informal social networks (such as clubs and organizations) within the community. A more autarkic system state would be an elaborated structure of overlapping social networks and active citizenry. For energy autarky associations or clubs specifically on energy or sustainability topics are particular important. An elaborate structure of multiple overlapping networks in the demo sites need to be compared with other locations. This is not just about the number of associations or clubs that exist (organisation grade), but also their diversity and the growth of interaction among citizens.

A change to more autarky would be:

- a higher citizens organisation grade in the demo sites;
- more sustainability and energy related kinds of associations or clubs exist within the project demo community;
- more interaction between community members in general
- more interaction in specific sustainability and energy platforms.

5.5.2 Energy and land regulations

The second social-regulatory dimension are the energy and land regulations. Autarkic communities are realized and developed in a legislative and regulatory context (e.g., energy market regulations, system operation regulations). The autarkic system state strived for is a high degree of regulatory freedom to experiment and implement local solutions independently. For instance, if it is permissible to exchange energy directly within the community, which normally is not allowed by law. A higher level of autarky comes from some forms of experimentation permits or sandbox regulation that sets existing energy law a site for specific energy system choices in the local energy systems in the demo sites.

5.5.3 Sophistication of self-governance

The third social-regulatory dimension is the sophistication of self-governance. If a local community has become more autarkic this should show by a higher level of local community autonomy, to govern on its own initiative, the local (energy) affairs of its community. The ability to govern more on its own initiative depends on:

- local powers given to the local community;
- the local community operating on the energy market:
- the influence of community members on the community decisions concerning energy (democracy).

Local powers depend on national regulation. In general, the powers of local authorities with respect to energy and climate matters vary greatly from one country to another. History and the resulting administrative organization of each country have determined the relative weight of local power (Coenen & Menkveld, 2002). In general, more self-governance follows from the subsidiarity principle. The principle of subsidiarity ensures that decisions are taken as closely as possible to the citizen. Actions are related to the possibilities available at local and community level. Unless it is clearly more effective to take action at higher national or regional level, competences fall to the local or community level. Further self-governance also depends on the local financial capacity and local knowledge capacity. The room to manoeuvre within national regulation depends on the financial means and the available knowledge to undertake action.

The more access local communities have to enter the energy market on a level playing field, the more they can manage their own energy affairs. The EU has recognized energy communities as a way to organize collective energy activities. Energy communities as legal forms can play a central role in the local energy market though a wide range of energy activities. By organising these activities there is a larger possibility to organise the own community affairs, like owning energy production and deciding about energy investments in the community.

The influence of community members on the community decisions concerning energy is part of representative democracy processes. Besides this representative democracy there might be participatory democracy in place through a sperate formal citizens' representation within the community, or through specific rules that guide interactions and energy management within the community. Because local energy communities are based on democratic participation and decision-making by its local stakeholders, they make it easy for citizens to become involved in their local energy system.

A change towards more self-governance would be:

- more local power in regulations and policies;
- more local energy community members;
- more prosumers;
- more participatory democracy through formal representation and participation interactions.
-

5.5.4 Alignment of energy values

The fourth social-regulatory dimension is the alignment of energy values. If a local community has become more autarkic this should show through a high degree of agreement and alignment of values related to the autarkic energy system within the community. People have different energy- and climate-related social values. For some people the ideal is powering their homes using a small renewable energy system that is not connected to the electricity grid as stand-alone system to their environmental values. For others this stand-alone should be organised on the community level because of energy security and affordability reasons. Others might have a less sustainable underlying motivation and value, and their motive might come from economic reasons while they think it makes economically sense be more autarkic as community. Or they might distrust energy providers. The more the values concerning self-sufficiency are synchronised towards a common value of self-sufficiency and autarky and/or there is less diversity in these values the more the community has moved towards autarky.

5.5.5 Scope of autarky aspirations

The fifth social-regulatory dimension is the scope of autarky aspirations. A more autarkic system state would be a broad envisioned scope of autarky. First this broader scope next to the general aim of 100% energy autarky, is that there is also autarky in time, so a daily, seasonal or yearly net zero balance and self-sufficient system not using the grid for back-up for certain periods. Secondly, to reduce any influence from outside on the (energy) functioning of the community, also autarky in terms of self-sufficiency in other services like food provision, economic system, and mobility is relevant. Indicator for full autarky is a broad scope in self-sufficiency and independence in other but related sectors than energy, like food, water and mobility. Full autarky, can be expected for especially the two Indian village demonstrators. However, it has to be stated, that full autarky is not necessarily the goal for the other demonstration sites, since flexibility provision to the grid is a main issue for instance for the Danish demonstrator, and therefore the goal is merely on sustainability and 100% RES provision, no matter if the RES is produces locally or not.

6 Studying the innovations in the demo sites

In the SUSTENANCE project we introduce and manage innovations in the existing local energy systems in the demo sites to create a purposeful change towards a local, sustainable and efficient integrated energy systems with more autarchy. Because we see the local energy system as a socio--technical system we do not just want to learn about technical aspects but also about social cultural aspect like acceptability and usability and social regulative, political and economic factors.

A more autarkic system is also a change in the way of thinking about the use and the importance of energy in the specific context of the demo sites as it might ask for changes in the community culture (ways of thinking, values, reference frameworks, etc.), the local energy system practices (habits, ways of doing things, etc.) and local energy system institutions (norms, rules, etc.). The innovations will influence the set of culture, practices and institutions related to the new innovation.

We study the innovations in the demo sites differently, but not separately from the demo sites. They are units of analysis embedded within the demo sites (see chapter 5). The innovation process is as unit of analysis to help us to understand how change is happening within the system (process), and to see what innovations have the possibility to make changes and shifts in the system (create effects). The evaluation of the innovations are a combination of an effect and process evaluation. In the demo sites innovations are undertaken in a real life setting to test them outside the laboratory and improve these innovations.

Our particular way of doing an innovation study is not just focussing on the success of the innovation as such, but also on the contribution of the innovation to system change. What takes place at a small scale eventually should trigger changes at a wider scale. This depends on the maturity of the innovations and in how far the innovations have proven themselves in the experimentation in the demo sites. For the level of proven innovation we will use the concepts of technological and social readiness level.

We study the innovations in the demo sites with the help of concepts from strategic niche management (SNM) as introduced in deliverable 3.1 of the SUSTENANCE project. Schot, Slob, and Hoogma (1996) define SNM as learning about niches and *developing the application rate of technologies through the creation, development and controlled phase out of protected spaces*. It is thus about the development of niche innovations. We have chosen to use the SNM approach to study underlying processes of the innovations in the local energy system driving system change. In the following subsections five aspects of studying innovations will be introduced:

- experiments and niches;
- stimulating system change;
- protection of and support for innovations;
- actor involvement;
- role of evaluation of niche innovations in dissemination.

6.1.1 Experiments and niches

We see the technical and social innovation in the demonstrator sites as ’experiments’ and niches in the regime of the local energy system. The aim of these experiments is to learn about and improve the innovation on multiple dimensions, not only the technical, economic, market demand and usability aspects, but also the political, regulative, and environmental. In deliverable 3.1 of the SUSTENANCE project we already introduced the concepts of regime, niche and landscape and the so-called multi-level perspective on transitions (Geels, 2002, 2005). Geels described the dynamics around niches as interactions between three different functional levels: the socio-technical regime (meso level) which refers to the dominant and relatively stable set of culture, practices and institutions related to a specific field (e.g., mobility or energy). Landscape (macro level) represents the social, economic and political context in which actors interact and regimes and niches evolve. On the niche (micro level), in a protected space “isolated” from the influence of the dominant regime, radical innovations can be tested, become more mature, and potentially challenge and change regime practices and institutions. In literature socio-technical experimentation is linked with radical innovations: innovations that require substantial changes on various dimensions (socio-cultural, technological, regulative and institutional). (Geels 2002, 2005). In deliverables 3.1 and 3.2 of the SUSTENANCE project we already distinguish several barriers and conditions for system changes. The innovations seen as experiments can also serve to identify the various resistances and barriers (institutional, regulative, economic, etc.) that can potentially hinder the future implementation and diffusion of innovations and understand how to address these barriers.

6.1.2 Stimulating system change

In the SNM literature, technological niches are intentionally created protected spaces for learning about new technologies (Geels, 2002). Niches can act as “incubation rooms” for radical novelties (Geels, 2002), where socio-technical experimentation and learning processes take place. As mentioned before in the SNM framework we not only study the success of the innovations and the barriers and conditions they face, we also look in how far they contribute to system change. The socio-technical experiments are not only aimed at testing and improving the innovation, but also at stimulating changes in the socio-technical context, in order to create the most favourable conditions for the innovation. In other words, experiments are also strategically used to influence contextual conditions in order to favour and hasten the societal embedding process (for example, by influencing local administrations to adopt policy measures that support the innovation, or stimulating potential users to change their behaviours and routines). In deliverable 3.1, we used the concept of local energy system change. However, our innovations are not just there to mature within the demo sites but are according to the theory of SNM a crucial step towards a regime shift.

In principle, a local energy system change is a transition as we discussed in section 3, but the system change we are particular studying here spans a shorter project period in which we cannot see a full transition of the whole system. (Rip & Kemp, 1998, Hoogma, Kemp, Schot, & Truffer, 2002). Our demo sites are in different phases of transition (Loorbach and Rotmans, 2010) (see section 3), but mostly still in the start-up phase.

Kemp, Schot, and Hoogma (1998) distinguish four stages of regime transition within SNM: (1) the selection of an experiment, (2) the set-up of the experiment, (3) scaling up the of the experiment, and (4) breakdown of the protection of the experiment (the more the experiments mature, the less of protection in terms of subsidies an specific regulation they will need, which will only limited happend within the SUSTENANCE project timeframe. The results of the innovation are changes in the local energy system, defined in section 5 as project goals and system effects and a change in the autarky status.

6.1.3 Protection of and support for innovations;

To be able to conduct socio-technical experiments the SNM framework advocates protection of the innovation and support in the phase of experimentation. The more radical innovations are the more likely that they would not survive or work out without this protection. Niches experiments can shield radical innovations from market competition and allow continuous experimentation to lead innovations to mature in their improvement function (Schot & Hoogma, 1996). The idea is to temporarily shield the innovation from the selection pressure (which consists of markets and institutional factors), creating an alternative selection environment. Although we are ultimately looking for economically viable innovations, future profits or social benefits might still be uncertain early in the project. Unless actors want to invest in technological innovation without any direct commercial benefits, financial protection and support is important to facilitate investments in early applications. The demonstrator sites provide the necessary protection for niche innovation. There are different forms of protection: financial protection (such as strategic investments by companies, tax exemptions, and investment grants) and socio-institutional protection (such as the adoption of specific regulations). The crucial dilemma of protection measures is to find the right balance between the need to nurture the innovation and the need to prepare it for the selection pressures of a market environment (Weber, Hoogma, Lane, & Schot, 1999)

6.1.4 Actor involvement

For the development of niches the involved actors are crucial. Kemp et al. (1998) distinguished three steps in niche forming: (1) aligning expectations, (2) learning through sharing information and lessons learnt, and (3) forming networks. An important aspect of the idea of using local experimentation in SNM is the role of expectations and visions (Raven et.al., 2016). Niches show the possibilities of doing things differently than in the existing regime, in our case related to the switch from fossil fuels to RES. Articulating expectations reduces uncertainty in the innovation process (Schot & Geels, 2007, 2008). The vision allows mobilization of resources by other actors by providing them promises about future benefits (Geels and Schot, 2007). However, not all of these niches will bring about a radical change in the regime in the short term of three years.

Besides expectations and visions, another crucial element for niche development are networks (Raven, Bos & Weterings, 2010). Experimentation aims to align the expectations of different actors in the system. In niche experimentation, social networks are considered important because the actors in the network provide necessary resources to sustain niche development. Further, actors in the network are important for the formulation of requirements and demands. Networks are also important for enabling learning and diffusion of lessons and experiences between network actors. Such networks might additionally include actors related to the larger regime, who might even be necessary in terms of resources and support. However, networks dominated by regime actors might lead to incumbent actors blocking the niche development.

6.1.5 Role of evaluation of niche innovation in dissemination

The basic idea of the experimentation with niche innovation within an intentionally created protected space is that this is a crucial step towards more mature innovations. The niche innovations have the inherent element of showing that things can be done differently. Experimentation is a way to help articulate and change expectations of actors of the benefits to expect from the innovations. Protected spaces are important because the existing regimes would otherwise reject those innovations as economically not viable or not socially acceptable and prevent the innovations from becoming mature. What we cannot do in the project, given the time span, is to see whether the current regime will be broken and replaced by a niche regime. The demonstrator sites provide the necessary protection for niche innovation. Eventually, however, innovations need to be selectively exposed to market pressures (Kemp et al., 2001). An innovation should not remain unnecessarily long in place if it shows that it lacks social acceptability and economic feasibility. Learning in our project is not just for the local actors in terms of local experiments, we also want to disseminate the results of the local experiments to actors outside of project. Geels and Raven (2006) have conceptualized how experiments and niches relate and develop over longer periods of time. They make a distinction between local experiments and a 'global' niche and outline different forms of learning for different actors. Local niche development in this distinction relates to experimentation in local contexts supported by local networks and generating locally applicable lessons. This is where most of our evaluation work in the demonstrators lies. The so-called 'global' niche refers to a network of actors that is concerned with knowledge exchange transcending local contexts and interacting with the wider world (Geels & Raven, 2006). Here, actors outside of the demonstrator sites, such as industry platforms, user-groups and other intermediary organizations play a role (Grin, Rotmans, & Schot, 2010). The BRIDGE initiative can play such a role in the SUSTENANCE project.

WP9 of the SUSTENANCE project will investigate the replication and scale-up possibilities of the SUSTENANCE innovation activities for the creation of benchmark models and innovation pathways. The evaluation framework in this deliverable concerns the results of the demo sites. In this deliverable the questions are about the process in the demo sites, with questions like in how far experiments are designed and supported by regime insiders or outsiders, in how far the niches were intentionally shaped by an intervention program and by whom, and in how far the new interventions are a break with the past. Eventually, we want to go beyond the processes in the demo sites to generalize the applied innovative technological, environmental, institutional and socio-economic solutions in other contexts.

For WP9 we will need additional questions about:

- access to new markets;
- new business opportunities for citizens, industry and utilities;
- collaboration in networks and clusters;
- development in turnover for involved industries;
- research findings and novelty;
- consumer acceptance and engagement;
- influence in local communities and municipalities;
- influence on regulation and legal constraints.

6.2 Demo sites process evaluation questions

The application of the innovative and enhanced technological, socioeconomic and environmental solutions developed in the project are established through the real-life demonstrators (WP4, WP5, WP6 and WP7). The progress and impact of the solutions are related to the system change we strive for, but they also need to be monitored for their commercial possibilities, social and market requirements and its advancement through the technology readiness levels.

The SUSTENANCE project targets to build sustainable and low carbon integrated energy communities in the different demonstration sites by implementing innovative socio-economic tools, technological solutions, environmental friendly schemes, and ownership and business models, resulting in benchmark techno-socio-economic solutions.

The project fits to TRL 5-8, of the General Annex G of the work programme. The testing and validation of the developed models, control schemes and technological solutions for the smart interfaces of multi-vector energy systems in the different sites of the four demonstrators qualify as TRL 5-6 *("technology* validated*/demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies")*. The implementation of socio-economic mechanisms, integration tests and demonstration of local cross-sector energy island installations in the various communities qualify as TRL7 *("system prototype demonstration in operational environment"*).

The setup of energy communities with the active participation of its citizens and energy stakeholders, understanding their outlook and acceptance levels of the local energy system transformation, leads to replicable systems, tools and solutions for efficiently establishing and operating other local energy community systems in wide-ranging locations leading to TRL 8 *("system complete and qualified").* In a span of 3-4 years from the project end, the experiences learned and knowledge acquired from the various installations, is expected to enlarge the application of these innovations as TRL 9 as enhanced proven products and services in more broader operational setups and environment.

Besides the technological readiness in the cross-cutting WPs (WP2, WP3, WP8 and WP9), strong emphasis are given to identify and adopt the relevant techno-socio-economic, environmental, legal and regulatory factors that effects the accomplishment of innovation and commercialisation of the project solutions. Societal Readiness Level (SRL) is a way of assessing the level of societal adaptation (Wullum Nielsen et. al. 2018). If the societal readiness for the social or technical solution is expected to be low, suggestions for a realistic transition towards societal adaptation are required. Naturally, the lower the societal adaptation is, the better the plan for transition must be. SRL 1 is the lowest and SRL 9 is the highest level. Levels SRL 1 – identifying problem and identifying societal readiness SRL 2 – formulation of problem, proposed solution(s) and potential impact, expected societal readiness; identifying relevant stakeholders for the project. SRL 3 – initial testing of proposed solution(s) together with relevant stakeholders SRL 4 – problem validated through pilot testing in relevant environment to substantiate proposed impact and societal readiness SRL 5 – proposed solution(s) validated, now by relevant stakeholders in the area SRL 6 – solution(s) demonstrated in relevant environment and in co-operation with relevant stakeholders to gain initial feedback on potential impact SRL 7 – refinement of project and/or solution and, if needed, retesting in relevant environment with relevant stakeholders SRL 8 – proposed solution(s) as well as a plan for societal adaptation complete and qualified SRL 9 – actual project solution(s) proven in relevant environment Stages SRL 1-3 reflect the early work in a research project, which is not so relevant for the SUSTENANCE project. For SUSTENANCE the stages SRL 4-6, representing actual solution(s) and testing them in the demo and use case context in co-operation with relevant stakeholders, while keeping a focus on impact and society's readiness for the product, is more relevant. In these stages the SUSTENANCE expectations on the societal adaptation must be described in specific terms and, to the extent possible, be part of the test phase. The stages SRL 7-9, that relate more to the end stages of a research project, includes refining the solution(s), implementation and dissemination of results and/or solution(s), is also relevant for some innovations in the SUSTENANCE project. Here the plan for addressing the societal readiness on a practical level to gain impact, creating awareness, disseminating results, etc., will be carried out

We use the SNM aspects and innovation management levels as inspiration for a number of evaluation questions:

Experiments and niches

- How are niche, regime and landscape related in the demo sites?
- How did the regime and landscape dynamics of the demo sites influence the experimentation?

Stimulating system change

- How mature have the innovations become (TRL, SRL)?
- What is the relation between the innovations and change in the local energy system?
- What is the relation between the innovations and the change in the autarky status of the local energy system?

Protection of and support for innovations

- Which limitations or obstacles influence the innovations?
- What kind of protections for the experiments are being used?

Actor involvement

- Who started the technological or social innovation initiative?
- Which actors are included in the network surrounding the innovation?
- In how far are the experiments designed and supported by regime insiders and or outsiders?
- In how far were the niches intentionally shaped by a policy program, and by whom?

Role of evaluation of niche innovations in dissemination.

- How mature are the technological innovations in terms of their TRL level?
- What was the role of expectations and visions in the initiative?
- In how far is the innovation a break with past practices?
- How ready are the demonstration site for the technical innovation (SRL)?
- What is needed to make the innovations a success?

7 Evaluation research design and methods

7.1 *Different evaluation elements*

In the SUSTENANCE project we try to assess the progress and impacts of the innovations in the demo sites towards carbon-neutrality of the local communities. We discussed a goal-free approach for the system change assessment. Goals are individual per demo site but might be comparable. But we do not start from these goals, but from an overview of all kinds of system effects and system characteristics change. This is a descriptive approach that gives a situation report of the system status. To see if changes are positive or negative or according to intentions, we would need evaluation criteria. Goals define what is positive or negative, and which actors are striving for such criteria. Goals are effects an actor wants to achieve. Besides what an actor wants to achieve, there is also the element of what an actor thinks he can achieve. In a strict goal free evaluation the risk is that the evaluator goals are implicitly introduced as criteria.

We described in the previous sections six different evaluation elements of change in the local energy systems.

1. Describing system changes, in term of system effects and system characteristics.
2. Goal achievement on the SUSTENANCE project goals for the local energy systems in the demo sites, formulated as carbon-neutrality, decentralization, sustainability, efficiency and energy integration.
3. Goal achievement on the local energy system goals from the actors in the cases. This is per definition a selection of all effects that are shown by the situation report and they might overlap with the project goals.
4. Describing the autarkic system state for different autarkic dimensions
5. Describing factors influencing the innovations and innovation management in the demo sites
6. Assessment of the relation between the innovations in the demo sites and the system changes.

In aspect 1, 4 and 5 we point by using the word describing, to a goal free evaluation of the changes. In aspect 2 and 3 the wording goal achievement points to a selection of the changes and their effects based on the changes and effects actors want to achieve. We use the wording '*assessing*' the relation, to avoid suggesting that this aspect is about correlation or even causation. These six evaluation aspects are interrelated because they as part of the same cases.

7.2 *Case study design*

We see our demo sites as different experiments in building carbon-neutral energy communities. As research design we follow a (embedded) case study approach. Within the demo sites, as different experiments in building carbon-neutral energy communities, they have a different set of experimental innovations to bring a system change towards carbon-neutral energy communities. The different interventions are the way the demo sites establish local, sustainable and efficient integrated energy systems. An embedded case study is a case study containing more than one sub-unit of analysis (Yin, 2003). Within the demo sites as cases we have the demo site innovation processes as sub-units. The distinction between the demo-sites as case and the innovation processes as separate subunits allows for a more detailed level of research into the innovation processes.

A case study research methodology *relies on multiple sources of evidence to add breadth and depth to data collection, to assist in bringing a richness of data together in an apex of understanding through* *triangulation, and to contribute to the validity of the research* (Yin, 2003). In a case study we can integrate quantitative and qualitative methods into a single research study (Yin 2003). The unique strength of this approach is this ability to combine a variety of information sources including documentation, interviews, and artifacts (e.g., technology or tools).

To understand a particular local energy system, mapping the system effects and system characteristics is a useful start. Once we understand the sense of the system, it is easier to set criteria for an evaluation. In section 5 and 6 we already introduced a set of questions to help focus the effects and substance evaluation of the demo sites, and the process evaluation of the innovations in the demo sites.

7.3 Case comparison of the demo sites

Our case studies are the demo sites with different local energy communities and physical and socio-technical characteristics. Key of the methodology for analysing the demo sites as our case studies, is a cross-case analysis as a research method that facilitates the comparison of commonalities and difference in the events, activities, and processes that are the units of analyses in the demo sites.

We do not have demo sites where interventions (different innovations) towards carbon-neutral energy communities do and do not take place. In an experimental design, the way of reasoning is, that to learn more about whether a system intervention is responsible for the observed changes in the experiments is a comparison of these experiments being investigated to a control group that has not been exposed to the intervention. The idea is that the probability of other events than the system intervention causing the observed changes is reduced, since these must have happened in both the experiment group and the control group. In principle an experimental research design is a research method used to investigate the interaction between independent and dependent variables, which can be used to determine a cause-and-effect relationship. A correlational research design investigates relationships between variables without the researcher controlling or manipulating any of them. A correlation reflects the strength and/or direction of the relationship between two (or more) variables. The demo sites with a different score on the autarky characteristics have different autarky profiles. We do not have an experiment demo sites case with a very high level of autarky characteristics to be compared with a control case with no autarky characteristics. The demo case autarky profile is a status of the different system we can compare. And we can look if certain innovations' lead to more autarky on a certain dimension, but there is no causations or logical intervention that would lead system change as a whole.

7.4 Case comparison of the innovations

We are trying to understand how changes are happening within the systems. And how innovations initiate changes and shifts in the systems. We can see this as a journey this innovation takes or the pathways the innovation follows. The demo case give us possibilities for comparing and contrasting the journey or pathway of innovations in the demos. To be able to generalise the effects of the evaluations we are looking for leverage points and system conditions. In systems thinking a leverage point is a place in a system's structure where a solution element can be applied. A high leverage point offers the change for a small amount of change force to causes a large change in system behaviour.

7.5 Data collection

Data collection is the process of gathering, measuring, and analyzing data. The data collection depends on the elements of the evaluation framework.

For <u>describing the system and system changes</u>, in term of system effects and system characteristics, both qualitative and quantitative data will be used. System change of the socio part of the socio-technical systems is not only about numerical data, like socio-economic, but also about qualitative data like change in behaviour or beliefs of actors. A broad range of data collection methods, ranging from secondary analysis of existing social-economic data, surveys, interviews with stakeholders and inhabitants, focus groups with citizens and participatory observations will be used.

For measuring goal achievement on the SUSTENANCE project goals and on the local energy system goals from the actors in the cases, data will be collected on the effects mentioned in the goals. Goals are about effects the project or actors in the demo want to attain. Only part of the effects, like CO2-reduction or energy production, can be quantitatively measured. Other effects, such as the 'local communities democratic principles and 'level of energy self-governance' are more difficult to quantify. In principle to measure quantitative goal achievement, we need to compare the baseline situation at the beginning of the start of the demo case, the envisioned situation in the future with the local energy system, and the achieved situation at the end of the relevant evaluation period. Quantitative data will be collected with secondary analysis of existing data bases. Next to the secondary data collection, we use a survey for primary data collection. The population survey (draft in Annex A) is not only aimed at the population of the demonstrator sites, but also at the wider community. First to use the wider community as a control group to compare with the demo sites. Secondly, because the population of the demo sites is rather small, the wider community also gives us a better idea of how people in the different countries and specifically in the demo site municipalities think about energy and climate, their priorities and their energy related behaviour. The goal of the survey is to collect data on economic and political attitudes towards local, clean, and security of energy and to gather demographic data as background information to support tasks in WP3. The survey analysis will be particularly reflected in deliverable 3.5 on the social acceptability of the transition. And to see at the end of the project if attitudes and other socio-economic variables have been changed.

For describing the autarkic system state, we need to collect data for the indicators for the different autarkic dimensions. As we have seen in section 5 some indicators for these dimensions are quantitative and some dimensions already have clearer indicators than others. Further work is needed on these indicators. For the different indicators we will need different data collection methods. For some indicators specific questions are added to the survey.

For describing factors influencing the innovations and innovation management in the demo sites we need data to understand the context in which the innovations operate. We study the innovations in the demo sites with the help of concepts from strategic niche management. We look into the creation, development and (protected) application of niche innovations. This about activities of actors and about external factors that influence the niche innovation. We introduced with the help of SNM concepts a number of evaluation questions. These are mostly process evaluation questions on who what, when, where, why, and how in the innovation processes that require qualitative data collection through surveys, interviews and participatory observations.

Finally, we assess the relation between the innovations in the demo sites and the system. System change means a difference in the state of the local energy system on different points of time. Innovation in itself can also be seen as a change. Innovations are changes on itself in terms of new energy infrastructure or new processes introduced to the local energy system. This evaluation element is about the impact of the innovation on the local energy system. However, we try not to determine whether the change can be ascribed to the innovations or to some other explanation, i.e., we are not looking to establish causality relation. The approach is more trying to understand how the innovations are viewed by different actors.

8 Framework

The key to our approach to assessing the local system change in the demo sites is the idea of a systemic evaluation, bringing different evaluation criteria and methods together, and the evaluation of niche innovations as the pathways to the local energy system change. We have seen in chapter 2 that the demonstrators are in different phases of transition (Loorbach, 2010) towards a sustainable energy system for achieving novel carbon neutral energy communities, but still at the start.

The evaluation framework is to assess if the energy systems in the demo sites evolved towards more carbon-neutral, local, sustainable and efficient integrated energy systems. Autarky is the characteristic of self-sufficiency applied to local communities and their local energy systems. The evaluation framework we present here is a basis to see in how far a higher stage of autarky is reached in the local energy systems.

The criteria of carbon-neutrality, decentralisation, sustainability, efficiency and energy system integration are all related to a higher stage of autarky of the local energy system. It is not only an aspect of the technical architecture of the system but also of the complementary socio-economic configuration of the local community.

For the purpose of our deliverable, we can see the demo sites as different experiments in building carbon-neutral energy communities. To move into a next phase of transition (Loorbach, 2010) towards a sustainable energy system for achieving a carbon neutral energy communities we need technical and social innovations. These innovations are the system interventions in the local energy systems in the demonstrator sites. The innovations are the sub-units of analyses with the embedded case research design with the local energy system as cases

We are not doing a policy (program) evaluation or are evaluating one (singled out) innovation, but instead, we are focusing on the interconnected components of the system. We are trying to understand how change is happening within the system. Effect evaluation is concerned with investigating effects. And what innovations have the capacity to initiate changes and shifts in the system. Our perspective in this understanding is the role of social factor. Social factors will influence the possibilities of technical innovations to change the local energy system and the role of (social) innovations themselves in changing the socio-technical system.

This evaluation framework provides a first framework for the set-up of evaluations and monitoring of the (social-economic changes) in the demo sites. And for the process evaluation of the different technical and social innovations which are the interventions in the system.

The six evaluation elements we introduced help us to answer the two questions:

1. In how far did social factors influence the possibilities of technical innovations to change the local energy system in the demonstrators towards more autarkic carbon-neutral energy communities?
2. In how far did social innovations change the local energy system in the demonstrators towards more autarkic carbon-neutral energy communities?

The first evaluation aspect, describing system changes, in term of system effects and system characteristics, is about the question <u>what change has happened in the system.</u>

The second evaluation elements is goal achievement on the SUSTENANCE project goals for the local energy systems in the demo sites, formulated as carbon-neutrality, decentralization, sustainability, efficiency and energy integration. We already introduced some preliminary quantitative and qualitative indicators for carbon-neutrality, decentralization, sustainability, efficiency and energy integration more autarkic carbon-neutral energy communities in section 5. For the evaluation in the demo sites, we have to further elaborate on these quantitative and qualitative indicators on the basis of details of the demo sites local energy systems. What change happened in the demo sites towards the project goals?

The third evaluation element, goal achievement on the local energy system goals from the actors in the cases, needs further elaboration with actors and stakeholders in the demo sites. This is per definition a selection of all effects that are shown by the situation report and they might overlap with the project goals. What change happened in the demo sites towards the local actor goals?

The fourth evaluation element, describing the autarkic system state for different autarkic dimensions, is the input for establishing the change in the local energy system in the demonstrators towards more autarkic carbon-neutral energy communities. What change happened in the demo sites towards a more autarkic system?

The fifth evaluation element, describing factors influencing the innovations and innovation management in the demo site, is input for understanding the influence of social factors on the technical innovations and input for the question did social factors influence the innovations? It is also about understanding the influence of external factors on the social innovations.

The sixth evaluation element, assessment of the relation between the innovations in the demo sites and the system changes, is input for the question did the innovations factors influence the change of the system?

For every demonstrator site in the SUSTENANCE project, we need to operationalize the overall framework of evaluation elements to the context and particular situation. Per demo sites these elements will be more operationalized in workshops with the partners in the demo sites and fitted to the partner expectations.

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9 Annex A Base survey

Survey Flow
Standard: Block 1 (1 Question)
Block: Demographic Questions (18 Questions)
Standard: Household Questions (30 Questions)
Standard: Behavior Questions (7 Questions)
Standard: Opinions about Energy and Climate (14 Questions)
Standard: Comments (1 Question)

Start of Block: Block 1

Introduction Title of Research Study: Building a Low Carbon, Climate Resilient Future: Secure, clean and efficient energy.

Investigator: Name of the University

What am I being asked to do?
You are being asked to participate in a research project that will survey you about your economic and political attitudes towards local, clean, and secure energy. The goal of this project is to understand people's energy use and their attitude towards sustainable and green energy transitions. The results of the survey will be used for internal and external reports as well as scholarly publication. All survey respondents will remain anonymous and will not be personally identifiable. This project is funded by the European Commission under the Horizon 2020. You will first report on your demographic information, then the questions will focus on your energy use and related concerns.

The survey has 83 questions and takes about 25 minutes. To participate in this study, you must also meet the following criteria:
1. You are 18 years old or older.
2. You have not taken this survey before.
3. You have agreed to participate in this survey.

What are the potential risks and benefits of participation?
There are no risks associated with participation in this study. There are no direct benefits associated with participation in this study.

What about privacy and confidentiality?
Because we do not ask for your name or other information that might uniquely identify you, the responses you provide can never be traced specifically to you. You will be identifiable using an anonymous ID number, not your personally identifiable information such as names and addresses.

Voluntary participation and withdrawal
Your participation in this study is completely voluntary. If you agree to be in the study, you may stop at any time. You may stop by exiting this web page or by simply closing your web browser. You may also skip any questions

you do not want to answer. If you do not complete the survey, or if we feel that you completed it to an unsatisfactory standard (i.e., you do not follow the instructions in the survey), we may ask you to retake the survey.

Who should I contact if I have questions?
If you have any questions, please feel free to contact the researchers: Frans Coenen (f.h.j.m.coenen@utwente.nl). If you have any questions about your rights as a human subject in this research, you may contact Frans Coenen (f.h.j.m.coenen@utwente.nl). We encourage you to print this consent form out for your records. By signing, you are agreeing to participate in this survey, and you will be taken to the beginning of the survey.

End of Block: Block 1

Start of Block: Demographic Questions

Q1. Are you a participant of the Serene or Sustenance Project?

- I am a participant of the Serene Project
- I am a participant of the Sustenance Project
- I am participating in both projects
- No

Q2 What is your age?

- ○ 18-30 (If you are under 18, stop. You should not take the survey)
- ○ 31-40
- ○ 41-50
- ○ 51-60
- ○ 61-70
- ○ Over 70

Q3 What is your gender?

- ○ Male
- ○ Female
- ○ Non-binary / third gender
- ○ Prefer not to say

Q4 Which city and country were you born in? Please specify.

Afghanistan
Albania
Algeria
Andorra
Angola
Antigua & Deps
Argentina
Armenia
Australia
Austria
Azerbaijan
Bahamas
Bahrain
Bangladesh
Barbados
Belarus
Belgium
Belize
Benin
Bhutan
Bolivia
Bosnia Herzegovina
Botswana
Brazil
Brunei
Bulgaria
Burkina
Burundi
Cambodia
Cameroon
Canada
Cape Verde
Central African Rep
Chad
Chile
China
Colombia
Comoros
Congo
Congo {Democratic Rep}
Costa Rica
Croatia
Cuba
Cyprus
Czech Republic

Denmark
Djibouti
Dominica
Dominican Republic
East Timor
Ecuador
Egypt
El Salvador
Equatorial Guinea
Eritrea
Estonia
Ethiopia
Fiji
Finland
France
Gabon
Gambia
Georgia
Germany
Ghana
Greece
Grenada
Guatemala
Guinea
Guinea-Bissau
Guyana
Haiti
Honduras
Hungary
Iceland
India
Indonesia
Iran
Iraq
Ireland {Republic}
Israel
Italy
Ivory Coast
Jamaica
Japan
Jordan
Kazakhstan
Kenya
Kiribati
Korea North
Korea South

Kosovo
Kuwait
Kyrgyzstan
Laos
Latvia
Lebanon
Lesotho
Liberia
Libya
Liechtenstein
Lithuania
Luxembourg
Macedonia
Madagascar
Malawi
Malaysia
Maldives
Mali
Malta
Marshall Islands
Mauritania
Mauritius
Mexico
Micronesia
Moldova
Monaco
Mongolia
Montenegro
Morocco
Mozambique
Myanmar, {Burma}
Namibia
Nauru
Nepal
Netherlands
New Zealand
Nicaragua
Niger
Nigeria
Norway
Oman
Pakistan
Palau
Panama
Papua New Guinea
Paraguay

Peru
Philippines
Poland
Portugal
Qatar
Romania
Russian Federation
Rwanda
St Kitts & Nevis
St Lucia
Saint Vincent & the Grenadines
Samoa
San Marino
Sao Tome & Principe
Saudi Arabia
Senegal
Serbia
Seychelles
Sierra Leone
Singapore
Slovakia
Slovenia
Solomon Islands
Somalia
South Africa
South Sudan
Spain
Sri Lanka
Sudan
Suriname
Swaziland
Sweden
Switzerland
Syria
Taiwan
Tajikistan
Tanzania
Thailand
Togo
Tonga
Trinidad & Tobago
Tunisia
Turkey
Turkmenistan
Tuvalu
Uganda

Ukraine
United Arab Emirates
United Kingdom
United States
Uruguay
Uzbekistan
Vanuatu
Vatican City
Venezuela
Vietnam
Yemen
Zambia
Zimbabwe

Q5 Are you currently living in the region that you were born in?

- Yes
- No
- I don't know
- Prefer not to say

Q6 What is your occupation? Please specify.

-- Select one --

Healthcare Practitioners and Technical Occupations:
- Chiropractor
- Dentist
- Dietitian or Nutritionist
- Optometrist
- Pharmacist
- Physician
- Physician Assistant
- Podiatrist
- Registered Nurse
- Therapist
- Veterinarian
- Health Technologist or Technician
- Other Healthcare Practitioners and Technical Occupation

Healthcare Support Occupations:
- Nursing, Psychiatric, or Home Health Aide
- Occupational and Physical Therapist Assistant or Aide
- Other Healthcare Support Occupation

Business, Executive, Management, and Financial Occupations:
- Chief Executive
- General and Operations Manager
- Advertising, Marketing, Promotions, Public Relations, and Sales Manager
- Operations Specialties Manager (e.g., IT or HR Manager)
- Construction Manager
- Engineering Manager
- Accountant, Auditor
- Business Operations or Financial Specialist
- Business Owner
- Other Business, Executive, Management, Financial Occupation

Architecture and Engineering Occupations:
- Architect, Surveyor, or Cartographer
- Engineer
- Other Architecture and Engineering Occupation

Education, Training, and Library Occupations:
- Postsecondary Teacher (e.g., College Professor)
- Primary, Secondary, or Special Education School Teacher
- Other Teacher or Instructor
- Other Education, Training, and Library Occupation

Other Professional Occupations:
- Arts, Design, Entertainment, Sports, and Media Occupations
- Computer Specialist, Mathematical Science
- Counselor, Social Worker, or Other Community and Social Service Specialist

- Lawyer, Judge
- Life Scientist (e.g., Animal, Food, Soil, or Biological Scientist, Zoologist)
- Physical Scientist (e.g., Astronomer, Physicist, Chemist, Hydrologist)
- Religious Worker (e.g., Clergy, Director of Religious Activities or Education)
- Social Scientist and Related Worker
- Other Professional Occupation

Office and Administrative Support Occupations:
- Supervisor of Administrative Support Workers
- Financial Clerk
- Secretary or Administrative Assistant
- Material Recording, Scheduling, and Dispatching Worker
- Other Office and Administrative Support Occupation

Services Occupations:
- Protective Service (e.g., Fire Fighting, Police Officer, Correctional Officer)
- Chef or Head Cook
- Cook or Food Preparation Worker
- Food and Beverage Serving Worker (e.g., Bartender, Waiter, Waitress)
- Building and Grounds Cleaning and Maintenance
- Personal Care and Service (e.g., Hairdresser, Flight Attendant, Concierge)
- Sales Supervisor, Retail Sales
- Retail Sales Worker
- Insurance Sales Agent
- Sales Representative
- Real Estate Sales Agent
- Other Services Occupation

Agriculture, Maintenance, Repair, and Skilled Crafts Occupations:
- Construction and Extraction (e.g., Construction Laborer, Electrician)
- Farming, Fishing, and Forestry
- Installation, Maintenance, and Repair
- Production Occupations
- Other Agriculture, Maintenance, Repair, and Skilled Crafts Occupation

Transportation Occupations:
- Aircraft Pilot or Flight Engineer
- Motor Vehicle Operator (e.g., Ambulance, Bus, Taxi, or Truck Driver)
- Other Transportation Occupation

Other Occupations:
- Military
- Homemaker
- Other Occupation
- Don't Know
- Not Applicable

Q7 How far do you commute to your work when not working at home?

- 0-5km (1)
- 6-30km (2)
- Longer than 30 km (3)
- I always work at home. (4)

Q8 What method of transportation do you use to commute? Choose all that apply.

- Car (1)
- Bus (2)
- Tram/Subway (3)
- Train (4)
- Walk (5)
- Bicycle (9)
- Other. Please specify. (6) ____

Q9 How much of your paid work is done at home?

- 0% (1)
- 1-20% (2)
- 21-40% (3)
- 41-60% (4)
- 61-80% (5)
- 81-100%

Q10 How would you describe your political views?

- ◯ Christian democrats (1)
- ◯ Social democrat (2)
- ◯ Liberals (3)
- ◯ Greens (4)
- ◯ Conservatives (5)
- ◯ Don’t know
- ◯ Don’t want to answer

Q11 What type of house do you live in?

- ◯ Apartments of 4 or less floors
- ◯ Apartments of 5 or more floors
- ◯ Two houses attached together
- ◯ Detached houses (3)
- ◯ 3 or more houses attached together
- ◯ Other. Please specify. (5) ____

Q12 How would you characterize the area where you currently live?

- ◯ Rural (1)
- ◯ City (urban) (3)
- ◯ Mixed
- ◯ Other. Please specify. (5) ____

Q13 Are you a member of local associations? Are you active in your community?

- Yes
- No
- Don't know

Q14 What kind of local associations themes are you active in? Choose all that apply.

- Buildings/Construction
- Environmental
- Infrastructure/neighborhoods
- Other, please specify

Q15 What energy matters are discussed commonly with your neighbors? Choose all that apply.

☐ Related to my home's private spaces (1)

☐ Related to my neighborhood's or building's common spaces (2)

☐ Related to public municipal spaces (3)

☐ None (4)

Q16 How are energy matters discussed with your neighbors? Choose all that apply.

☐ Informally (1)

☐ Citizen groups

☐ Neighborhood groups with municipalities

☐ Not discussed (4)

☐ Other please specify

Q17 How would you characterize the natural environment around in your neighborhood?

○ Substantial presence: abundant green and water elements (1)

○ Moderate: a few trees or other green and water spaces (2)

○ Minimal: mostly non-natural elements (3)

End of Block: Demographic Questions

Start of Block: Household Questions

Q18 How many people are earning in your household?

- ○ 0 (1)
- ○ 1 (2)
- ○ 2 (3)
- ○ 3 (4)
- ○ 4 (5)
- ○ 5 (6)
- ○ 6 or more (7)

Q19 What is your gross household income (before tax)?

- ○ Less than €5,000
- ○ €5,000 - €10,000 (1)
- ○ €10,000 - €20,000 (9)
- ○ €20,000 - €30,000 (2)
- ○ €30,000 - €40,000 (3)
- ○ €40,000 - €50,000 (4)
- ○ €50,000 - €100,000 (5)
- ○ €100,000 - €200,000 (6)
- ○ €200,000 or more (7)

Q20 How large is your house in square meters? (Excluding outdoor space such as gardens, balconies etc.)

- 0-30
- 31-50
- 51-100
- 101-150
- 151-250
- 251+

Q21 When was your home built?

- Before 1900 (1)
- Between 1900 - 1950 (2)
- Between 1951 - 1970 (3)
- 1970s (4)
- 1980s (5)
- 1990s (6)
- 2000-2010 (7)
- After 2010 (8)

Q22 When was your home last renovated?

- My home has not been renovated
- Before 2000
- 2000-2010
- 2010-2022
- I don’t know

Q23 Do you own or rent your house/apartment?

- Own (1)
- Rent (2)
- Other arrangement. Please specify. (3) ____

Q24 How many people are residing in your house/apartment (your apartment unit, not the whole building)?

1

2

3

4

5

6

7

8

9

10

More than 10

Q25 How many of those people are minors (Aged 17 or less)?

○ 0 (1)

○ 1 (9)

○ 2 (2)

○ 3 (3)

○ 4 (4)

○ 5 (5)

○ 6 (6)

○ 7 (7)

○ More than 7 (8)

Q26 How many of those are aged 5 or less?

0 (1)

- 1 (9)
- 2 (2)
- 3 (3)
- 4 (4)
- 5 (5)
- 6 (6)
- 7 (7)
- More than 7 (8)

Q27 Did the number of household members change in the last two years?

- Yes, increased by three or more (1)
- Yes, increased by two (2)
- Yes, increased by one (3)
- No, the number of house members has not changed in the last two years (4)
- Yes, decreased by one (5)
- Yes, decreased by two (6)
- Yes, decreased by three or more

Q28 What is the gender division of the household members?

- Male only (1)
- Not male only, but male majority (e.g., two male, one female) (2)
- Gender balance (almost) (e.g., one male, one female) (3)
- Not female only, but female majority (e.g., two female, one male) (4)
- Female only (5)

Q29 What is your house's energy label?

- ○ A (1)
- ○ B (2)
- ○ C (3)
- ○ D (4)
- ○ E (5)
- ○ F (6)
- ○ G (7)
- ○ I don't know (8)

Q30 Do you use green or renewable electricity?

- Yes
- No
- I don’t know

Q31 Do you produce electricity (are you a prosumer)?

- Yes
- No
- I don’t know

Q32 What is the primary source of house heating system in your house? Choose all that apply.

- ○ Electrons (Electricity)(1)
- ○ Heat Pumps
- ○ District Heating
- ○ Natural Gas (7)
- ○ LPG
- ○ Biomethane (green gas) (8)
- ○ Oil (9)
- ○ Coal (11)
- ○ Lignite (12)
- ○ Biomass (including wood) (14)
- ○ Solar collector/solar tunnel (15)
- ○ I don't know (17)

Q33 Check all the appliances that you have in your house.

- ☐ Air conditioner (1)
- ☐ Air fryer (convection oven) (2)
- ☐ Blender (3)
- ☐ Clothes dryer (4)
- ☐ Clothes iron (5)
- ☐ Coffee maker (6)
- ☐ Dehumidifier (7)
- ☐ Deep fryer (8)
- ☐ Dish washer (9)
- ☐ Electric blanket (10)
- ☐ Electric water boiler (11)
- ☐ Electric heater (12)
- ☐ Food processor (13)
- ☐ Kitchen hood (14)
- ☐ Garbage disposer (15)
- ☐ Fan (attic, ceiling, fan heater, window) (16)
- ☐ Freezer (not refrigerator, freezer on its own) (17)
- ☐ Hair dryer (18)
- ☐ Humidifier (19)

- ☐ Juicer (20)
- ☐ Laptops/Desktops (21)
- ☐ Electric gardening tools (22)
- ☐ Microwave (23)
- ☐ Oven (24)
- ☐ Refrigerator (25)
- ☐ Sewing machine (26)
- ☐ Slow cooker (27)
- ☐ Gas stove (28)
- ☐ Electric stove (e.g., Induction)
- ☐ Coal/wood/other types of stove
- ☐ Television set (29)
- ☐ Vacuum cleaner (30)
- ☐ Washing machine (31)
- ☐ General wifi systems
- ☐ Air purifiers
- ☐ Heat recovering/insulation installation (e.g., Genvex systems)
- ☐ Game consoles

Q34 Check all the appliances that you use frequently (more than 1-2 times a month).

- ☐ Air conditioner (1)
- ☐ Air fryer (convection oven) (2)
- ☐ Blender (3)
- ☐ Clothes dryer (4)
- ☐ Clothes iron (5)
- ☐ Coffee maker (6)
- ☐ Dehumidifier (7)
- ☐ Deep fryer (8)
- ☐ Dish washer (9)
- ☐ Electric blanket (10)
- ☐ Electric water boiler (11)
- ☐ Electric heater (12)
- ☐ Food processor (13)
- ☐ Kitchen hood (14)
- ☐ Garbage disposer (15)
- ☐ Fan (attic, ceiling, fan heater, window) (16)
- ☐ Freezer (not refrigerator, freezer on its own) (17)
- ☐ Hair dryer (18)
- ☐ Humidifier (19)

- ☐ Juicer (20)
- ☐ Laptops/Desktops (21)
- ☐ Electric gardening tools (22)
- ☐ Microwave (23)
- ☐ Oven (24)
- ☐ Refrigerator (25)
- ☐ Sewing machine (26)
- ☐ Slow cooker (27)
- ☐ Gas stove (28)
- ☐ Electric stove (e.g., Induction)
- ☐ Coal/wood/other types of stove
- ☐ Television set (29)
- ☐ Vacuum cleaner (30)
- ☐ Washing machine (31)
- ☐ General wifi systems
- ☐ Air purifiers
- ☐ Heat recovering/insulation installation (e.g., Genvex systems)

Game consoles

Q35 How much electricity does your household use per year? (in kWh) ____
Q36 How much money do you spend on heating per year?
Q37 How much do you pay for electricity per year? ____
Q38 How much money have you spent on electricity and heating in 2021?
Q39 How much money have you spent on electricity and heating in 2022?
Q40 Does your electricity supplier offer different tariffs for electricity depending on the time of day, for example at night (“off-peak” tariffs)? - Yes - No - I produce my own electricity
Q41 Does your household use a smart meter to record electricity use? - Yes - No - I don’t know
Q43 How many vehicles does your household have (rental, company car included)? ○ 0 (1) ○ 1 (2) ○ 2 (3) ○ 3 (4) ○ 4 (5) ○ 5 (6) ○ 6 or more

Q44 Of the vehicles that your household has, how many of them are electric vehicles (excluding hybrid vehicles)?

- ○ 0 (1)
- ○ 1 (2)
- ○ 2 (3)
- ○ 3 (4)
- ○ 4 (5)
- ○ 5 (6)
- ○ 6 or more

Q45 Of the vehicles that your household has, how many of them are hybrid vehicles including plug in vehicles (excluding electric vehicles)?

- ○ 0 (1)
- ○ 1 (2)
- ○ 2 (3)
- ○ 3 (4)
- ○ 4 (5)
- ○ 5 (6)
- ○ 6 or more

Q46 Do you charge your electric vehicle at home?

- I don't have an electric vehicle
- Yes
- No
- I don't know

Q47 When was your car produced? Check all that apply.

2022
2021
2020
2019
2018
2017
2016
2015
2014
2013
2012
2011
2010
2009
2008
2007
2006
2005
2004
2003
2002
2001
2000 or older

Q48 Do you have solar panels installed and currently producing electricity in your house?

- ○ Yes (1)
- ○ No, but I would like to
- ○ No (2)
- ○ I don't know (3)

Q49 If you said yes to owning solar panels, what is the system size of your solar panels? (in kW)

____

Q50 If you answered No / No, but I would like to: What is keeping you from getting solar panels installed on your house?
- I am not interested in producing my own electricity
- Getting solar panels installed is too expensive for me
- I don't think I have the required knowledge / it is too complicated for me
- Not possible because I do not own the house I'm living in (renting) / I like in an apartment building
- Other, please specify

Q51 Do you have any renewable energy generators other than solar panels on the house that you live in? Check all that they apply

- Wind turbines
- Solar heating (solar tunnel)
- Heat pump
- Biomass furnace
- Other, please specify

Q52 If you said yes to the two previous questions, was it difficult to interact with authorities to issue a permit and have them installed?

○ Easy (1)

○ Moderate (2)

○ Difficult (3)

○ Did not have to interact (4)

End of Block: Household Questions

Start of Block: Behavior Questions

Q53 I would like to lower my energy consumption.

○ Strongly disagree (1)

○ Disagree (2)

○ Neutral (3)

○ Agree (4)

○ Strongly Agree (5)

Q54 I view myself capable of realizing more energy savings (compared to now).

- ○ Strongly disagree (1)
- ○ Disagree (2)
- ○ Neutral (3)
- ○ Agree (4)
- ○ Strongly Agree (5)

Q55 I am willing to invest in renewable energy

- ○ Yes
- ○ No
- ○ I don't know

Q56 How much more are you willing to pay for renewable energy?

- ○ 1 - 5% (1)
- ○ 5 - 10% (2)
- ○ 10 - 15% (3)
- ○ More than 15% (4)
- ○ No intention to pay more (5)

Q57 Without any financial compensation, I am prepared to slightly adjust my behavior in order to make better use of sustainably produced electricity, for example by not using large household appliances during peak hours.

- ○ Strongly disagree (1)
- ○ Disagree (2)
- ○ Neutral (3)
- ○ Agree (4)
- ○ Strongly Agree (5)

Q58 If it saves me a few tens of euros per year, I am prepared to slightly adjust my behavior in order to make better use of sustainably produced electricity, for example by not using large household appliances during peak hours.

- Strongly disagree (1)
- Disagree (2)
- Neutral (3)
- Agree (4)
- Strongly Agree (5)

Q59 I am interested in installing a smart energy management system in my household, which can automatically reduce energy use or switch off appliances during peak hours.
- I already use a smart energy management system
- Yes
- No
- I don't know

Q60 If you answered No or I don't know to the previous question, what are the main concerns that keep you from wanting to use such a smart energy system?
[free text answer]

End of Block: Behavior Questions

Start of Block: Opinions about Energy and Climate

Q61 Production of renewable energy is important.

- Strongly disagree (1)
- Disagree (2)
- Neutral (3)
- Agree (4)
- Strongly Agree (5)

Q62 Lower energy price is more important to me than sustainable energy.

- Strongly disagree (1)
- Disagree (2)
- Neutral (3)
- Agree (4)
- Strongly Agree (5)

Q63 Environmental issues matter to me.

- Strongly disagree (1)
- Disagree (2)
- Neutral (3)
- Agree (4)
- Strongly Agree (5)

Q64 I support the use and development of nuclear energy.

- Strongly disagree (1)
- Disagree (2)
- Neutral (3)
- Agree (4)
- Strongly Agree (5)

Q65 I support the construction of new renewable energy projects (such as solar farms, wind turbines) in my community.

- Strongly disagree (1)
- Disagree (2)
- Neutral (3)
- Agree (4)
- Strongly Agree (5

Q66 Global climate change is important.

Strongly disagree (1)

Disagree (2)

Neutral (3)

Agree (4)

Strongly Agree (5)

Q67 It is best if initiatives come from local communities themselves.

Strongly disagree (1)

Disagree (2)

Neutral (3)

Agree (4)

Strongly Agree (5)

Q68 I would like my energy producer to be more locally controlled (e.g., communities, municipalities)

Strongly disagree (1)

Disagree (2)

Neutral (3)

Agree (4)

Strongly Agree (5)

Q69 National government policy mainly supports:

- Centralized power sources
- Decentralized
- Makes it difficult to have decentralized systems
- Mixed

None of the above

Q70 Saving energy (energy efficiency) is an important value in my social circle.

- Strongly disagree (1)
- Disagree (2)
- Neutral (3)
- Agree (4)
- Strongly Agree (5)

Q71 Generating one's own energy locally is an important value in my social circle.

- Strongly disagree (1)
- Disagree (2)
- Neutral (3)
- Agree (4)
- Strongly Agree (5)

Q72 The climate changes in my immediate surroundings (i.e., my home or my neighborhood) is an important factor for me in making energy related decisions.

- Yes, heatwaves (1)
- Yes, cold spells (2)
- Yes, both heatwaves and cold spells (3)
- No (4)
- I don't know (5)

Q73 I feel better if the energy system becomes more sustainable.

- Strongly disagree (1)
- Disagree (2)
- Neutral (3)
- Agree (4)
- Strongly Agree (5)

Q74 I like to participate in a common project together with the neighborhood to save or produce energy.

- Strongly disagree (1)
- Disagree (2)
- Neutral (3)
- Agree (4)
- Strongly Agree (5)

Q75 Decisions on the local energy system, such as energy sources and supply structures, should primarily be taken by: (select all that apply)

- Local government
- National government
- Local residents
- Local or regional energy utilities
- Private companies
- Others, please specify

Q76 I feel sufficiently well-informed to take decisions about my own energy supply.

- Strongly disagree
- Disagree
- Neutral
- Agree
- - Strongly Agree

Q77 I feel sufficiently well-informed to participate in decision-making for the energy system in my community, for example related to infrastructure development, network operation and energy trading.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Q78 The community where I live should be technologically able to share and store energy within our community and rely on the national energy system as little as possible

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Q79 In principle, 100% of the energy local demand in my community should be covered with local renewable energy

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Q80 My settlement should be self-sufficient in supplying residents' energy as well as recovering/recycling/disposing of our own waste/emissions

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Q81We should have a high degree of freedom to experiment and implement local energy solutions independently of national regulations in our community

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Q82 I prefer a high level of local community autonomy, to govern our local (energy) affairs on our own initiative.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

End of Block: Opinions about Energy and Climate

Start of Block: Comments

Q83 Thank you for completing the survey. If you would like to add any comments or questions regarding the survey or the Serene project, please write here.

____

End of Block: Comments