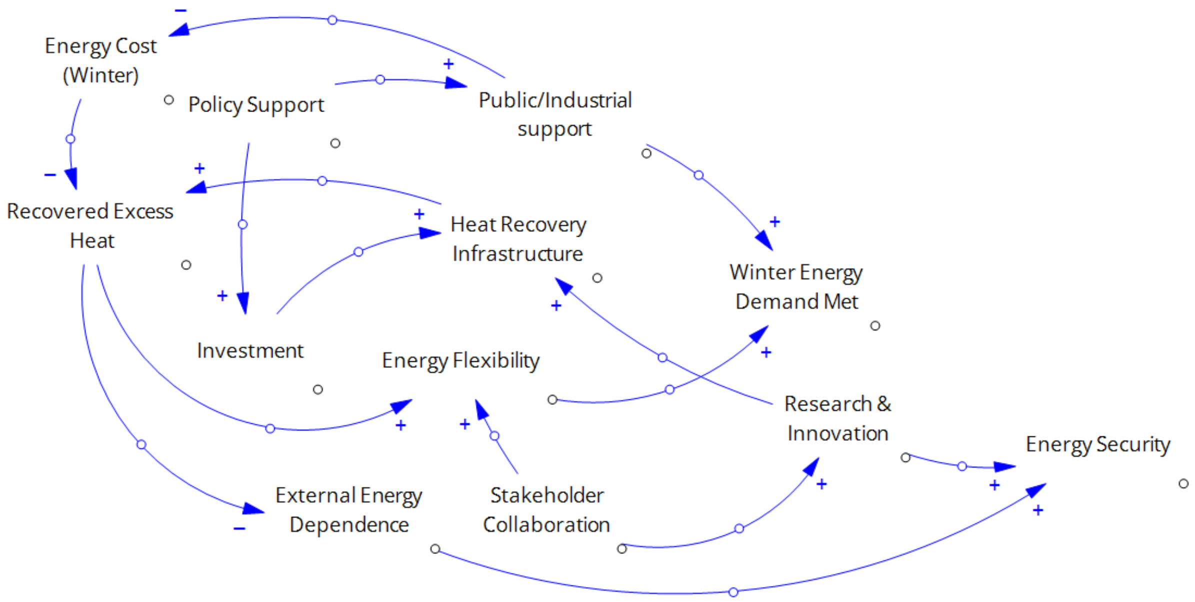


Transition Arenas

Systems mapping report: analysis of socio-technical systems in each pilot

Deliverable 2.2

2025.01.16.

Driving Urban Transitions

EUROPEAN PARTNERSHIP

Co-funded by the European Union

1. Table of contents

2. Introduction

This report presents the results of the systems mapping activities carried out within the framework of the ENERGY4ALL project, focusing on the socio-technical systems underlying the pilot innovations. As part of Work Package 2, Deliverable 2.2 aims to provide a structured, comparative analysis of how energy communities and related energy-sharing initiatives operate as complex systems shaped by interactions between social actors, technical infrastructures, economic incentives, and institutional frameworks. By applying systems thinking methods, the report seeks to uncover the key elements, relationships, and dynamics that influence both the performance of the pilots and the transferability of their innovations to other contexts.

At the core of this deliverable is the assumption that energy communities cannot be understood through isolated technical or economic parameters alone. Instead, they function as socio-technical systems in which outcomes emerge from the interplay of stakeholder interests, governance arrangements, behavioral patterns, regulatory environments, and technological configurations.[1] Systems mapping provides a methodological approach to capture this complexity in a structured way. It supports a shared understanding among project partners and stakeholders of "what matters" in each pilot, how different factors influence one another, and where potential leverage points for intervention or replication may lie.

The report builds primarily on qualitative data collected through Transition Arena (TA) workshops conducted at pilot level, complemented by structured questionnaires filled in by pilot teams and a subsequent review and synthesis process. These participatory methods were designed not only to collect information, but also to actively involve local stakeholders in reflecting on their own systems, thereby grounding the analysis in lived experience and contextual knowledge. Two closely connected analytical components structure the systems mapping work presented here: stakeholder mapping and causal loop diagramming.

The first main part of the report focuses on stakeholder mapping. It documents how relevant actors were identified, categorized, and analyzed in each pilot with respect to their roles, interests, influence, expectations, and relationships. Stakeholder mapping is treated as a foundational step for systems analysis, defining the social boundaries of the system and identifying key drivers, enablers, and constraints. The report details the data collection process, the qualitative analytical strategy applied (including coding and review procedures) and presents pilot-level results that highlight similarities and differences in stakeholder configurations across national and institutional contexts.

Building on this foundation, the second major part of the report introduces the use of Causal Loop Diagrams (CLDs) as a systems thinking tool to model dynamic interactions within each pilot. CLDs are used to visualize how variables identified by stakeholders are causally linked, to distinguish

[1] Hess, D. J. (2014). "Socio-energy systems design: A policy framework for complex sociotechnical challenges." Energy Research & Social Science, 1, 1-12

between drivers and outcomes, and to reveal reinforcing and balancing feedback loops. For each pilot case, the report presents and interprets the resulting CLDs, emphasizing how socio-technical dynamics shape energy-related outcomes such as participation, investment, energy demand, or system resilience.

The final sections of the report provide a cross-case comparison of the systems mapping results, identifying recurring patterns, contextual specificities, and key insights relevant for transferability and upscaling. By synthesizing stakeholder structures and causal dynamics across pilots, the report contributes to a deeper understanding of energy communities as socio-technical systems and lays the groundwork for subsequent analytical and strategic tasks within the ENERGY4ALL project.

3. Stakeholder mapping

3.1. Methodological Rationale

Stakeholder mapping carried out during the first Pilot-level Workshop was designed as an integral preparatory step for using the Causal Loop Diagram (CLD) methodology applied in WP2. Energy Communities (ECs) are formulated as complex socio-technical systems, in which outcomes emerge from interactions between social actors, technical infrastructures, economic incentives, and institutional frameworks. Within such systems, stakeholders are not merely background conditions but active system elements whose roles, interests, and power relations shape causal dynamics.

The purpose of stakeholder mapping at this stage was therefore not descriptive enumeration, but **systemic identification of actors who matter**, their relative influence, and their positions within the wider socio-technical configuration[2]. The results provide the empirical foundation for later CLD construction, where stakeholders' roles are translated into variables, causal pathways, and feedback structures.

Data Collection: Stakeholder Mapping Workshop

Stakeholder data were collected through facilitated, in-person pilot-level workshops involving direct stakeholders of each EC. The workshops followed a structured process aligned with the early phases of CLD development, particularly the identification of system elements and exploration of relationships.

Step 1: Stakeholder Identification

Participants collectively identified stakeholders who:

- are currently part of the energy community,
- may become part of the energy community in the future,
- affect the energy community from outside, or
- are affected by the activities and outcomes of the energy community.

This categorisation supported the definition of system boundaries and ensured that both internal and external actors were considered. Stakeholder identification was conducted through open brainstorming, supported by facilitation to clarify roles and avoid duplication.

[2] Prell, C., Hubacek, K., & Reed, M. (2007). "Stakeholder analysis and social network analysis in natural resource management." Society & Natural Resources, 20(3), 249-266.

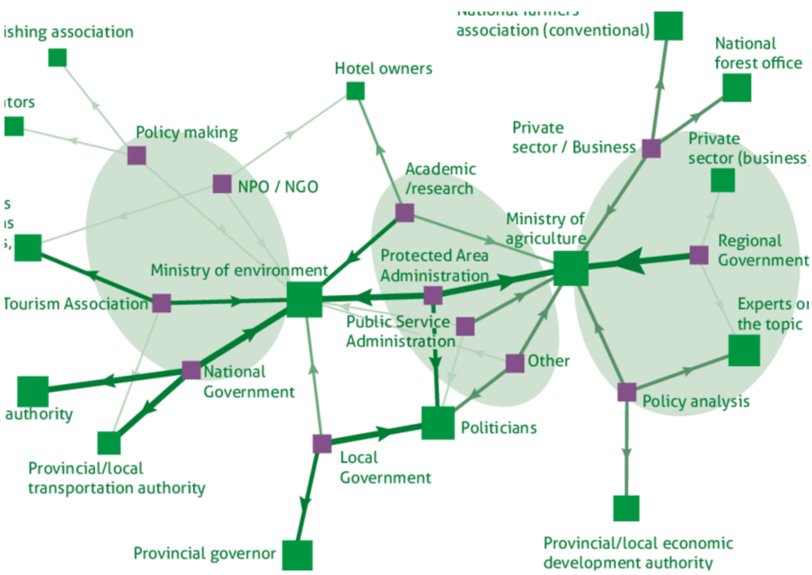


Figure 1 – Example stakeholder network identifying actors who matter[3]

Step 2: Stakeholder Mapping and Power–Interest Analysis

Identified stakeholders were analysed along two core dimensions:

- **Power / influence**, referring to a stakeholder's capacity to affect decisions, resources, or outcomes within the system;
- **Relevance / interest**, referring to the degree to which a stakeholder is affected by, or invested in, the development of the energy community.

Using visual mapping tools (e.g. matrices, post-it clustering), participants positioned stakeholders relative to one another. This exercise made visible asymmetries in influence, potential dependencies, and critical actors who may function as system drivers, gatekeepers, or bottlenecks. From a CLD perspective, this step supports the later distinction between drivers and outcomes within causal structures.

Step 3: Stakeholder Profiling

Key stakeholders identified during the mapping exercise were further analysed using a structured profiling template. For each selected actor, participants discussed and documented:

- role within the energy community,
- sources and degree of power or influence,

[3] Svadlenak-Gomez, Karin & Gerritsmann, Hanno & Badura, Marianne & Walzer, Chris. (2014). Biodiversity Stakeholder Networks in the Alpine Space. 10.13140/2.1.4695.8401.

- incentives and decision-making logics,
- expectations toward the energy community and reciprocal expectations,
- perceived risks and concerns,
- existing relationships, communication channels, and media of interaction.

These profiles provide qualitative depth to the stakeholder map and enable the translation of actor characteristics into system variables (e.g. trust, participation, regulatory support) during subsequent CLD construction.

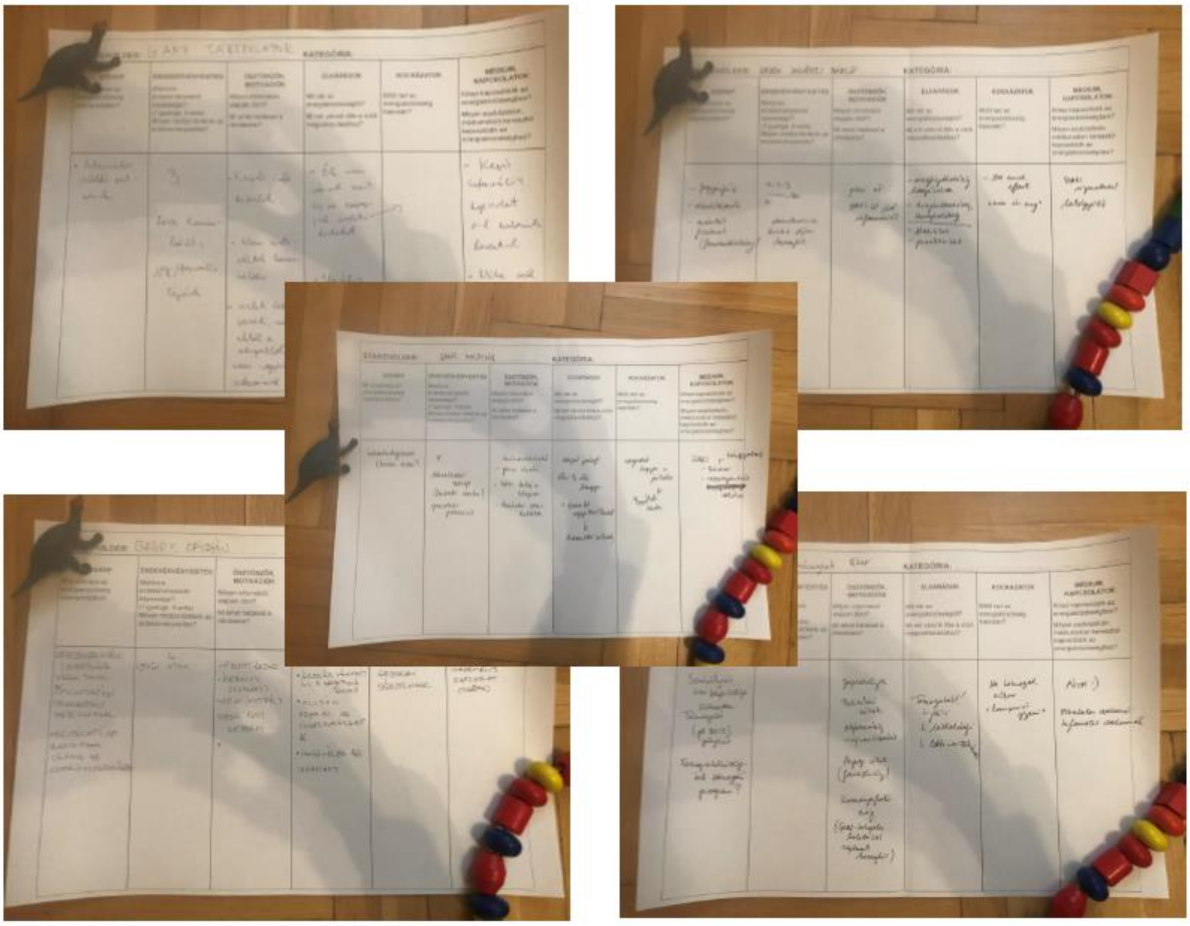


Figure 3 – Completed stakeholder profiling templates used during the workshop (Source: ABUD)

Questionnaires

A structured questionnaire complemented the workshop-based stakeholder mapping. It translated key analytical dimensions into a consistent format across pilots, supported triangulation of group discussions, and enabled cross-pilot comparison. Questionnaire data serves as an empirical bridge between qualitative workshop outputs and later CLD construction.

Analytical Strategy

Stakeholder mapping outputs – including filled out questionnaires, maps, matrices, and profiling sheets – were treated as analytical data. Materials produced during the workshops were reviewed and synthesised by researchers, with particular attention to:

- recurring patterns of power concentration,
- missing or weakly represented actors,
- tensions between stakeholder interests,
- implied causal relationships between actors and system outcomes.

Rather than producing a single static stakeholder list, the analysis focused on **relational configurations**, consistent with systems thinking and CLD logic. Stakeholders were interpreted as dynamic system components whose interactions may generate reinforcing or balancing effects once translated into causal models.

Role of Stakeholder Mapping in CLD Development

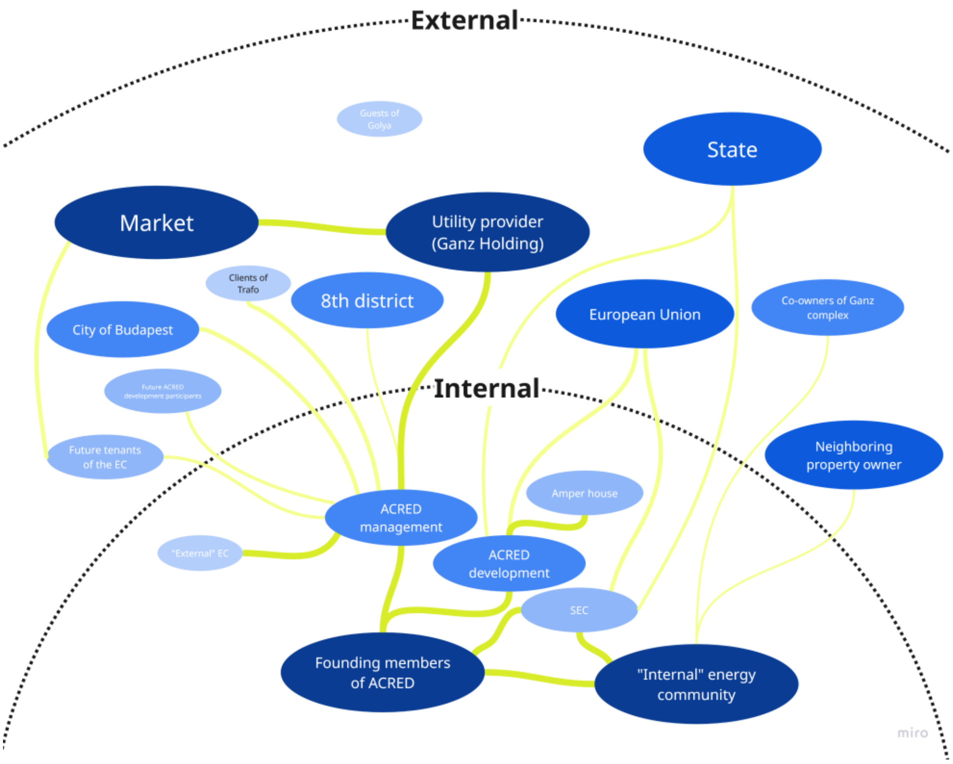
Within the overall CLD methodology, stakeholder mapping fulfils three key functions:

1. defining the social boundaries of the system under analysis;
2. identifying candidate drivers, enablers, and constraints;
3. grounding causal assumptions in stakeholder perspectives rather than abstract theory.

The results of the stakeholder mapping exercise directly inform later CLD steps, including variable identification, connection circles, and feedback loop analysis, thereby ensuring that causal models remain empirically grounded and context-sensitive.

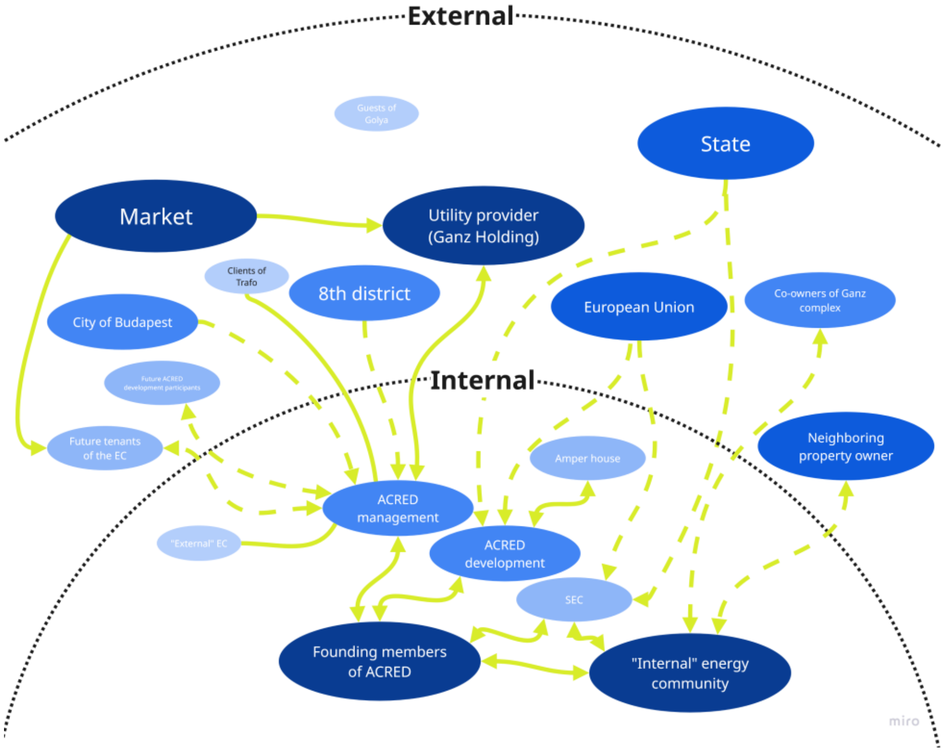
3.2. Pilot Case Studies – Stakeholder Analysis

3.2.1. Kazán Community House, Hungary



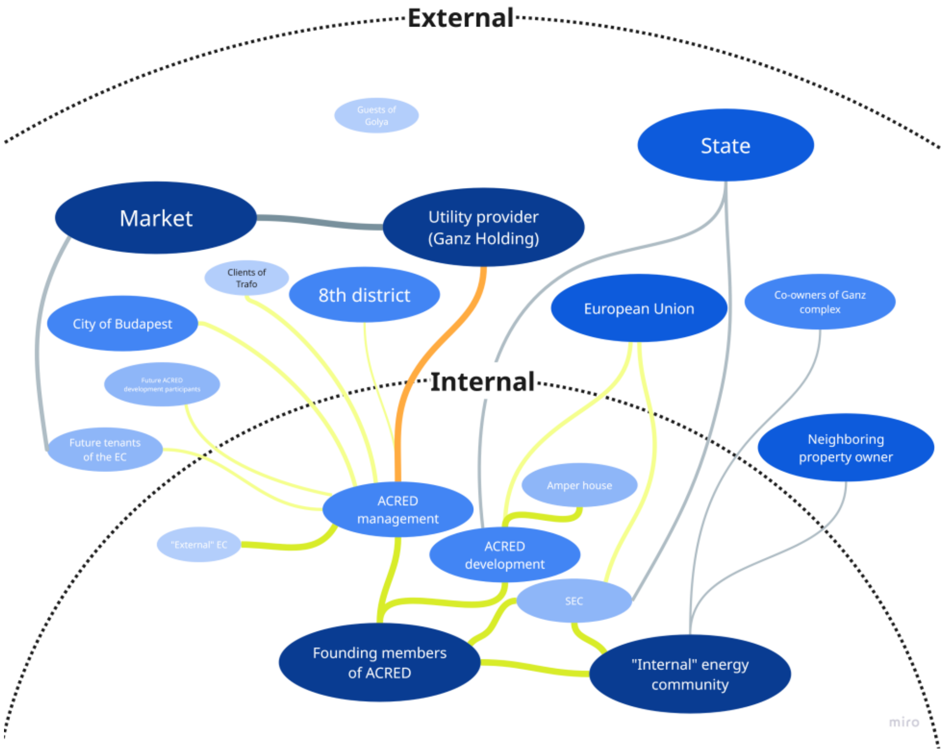
1. Figure Stakeholder relationships in Kazán case. Node size and saturation indicate power, edge size and saturation indicate strength of the relationship.

The core of the stakeholder network is ACRED, the alliance for community real estate development, the leaders of the project that created the energy community. It is split into a development and an asset management non-profit organization. ACRED consists of four organizations, with the solidarity economy centre (SEC) focusing on community energy. They created the energy community, which itself is a registered organization, including full members (internal community) and stakeholders with commenting rights (external community). Recently, a second, potential future energy community, the Amper house was initiated and incubated by ACRED development. On the development side, the most important external connections is the owner of the Ganz industrial building complex, part of which is occupied by ACRED tenants, also energy community members, partly by other tenants, and partly unoccupied. On the management side, Ganz Holding serves as the utility provider for the energy community, unlike for most non-industrial areas, which would be operated by a regular DSO.



2. Figure: Stakeholder communications in the Kazán case. Arrowheads indicate directionality of signals, dashed lines denote sporadic, full lines continuous communication.

Most communications in the network are bidirectional, except for the energy market, that "communicates" through price signals. Internal communication is sustained and day to day, whereas external stakeholders are interacting sporadically, with the most notable exception being Ganz Holding.



3. Figure: Stakeholder alignment in the Kazán case. Green lines indicate alignment, grey lines neutrality, orange lines adversarial relations.

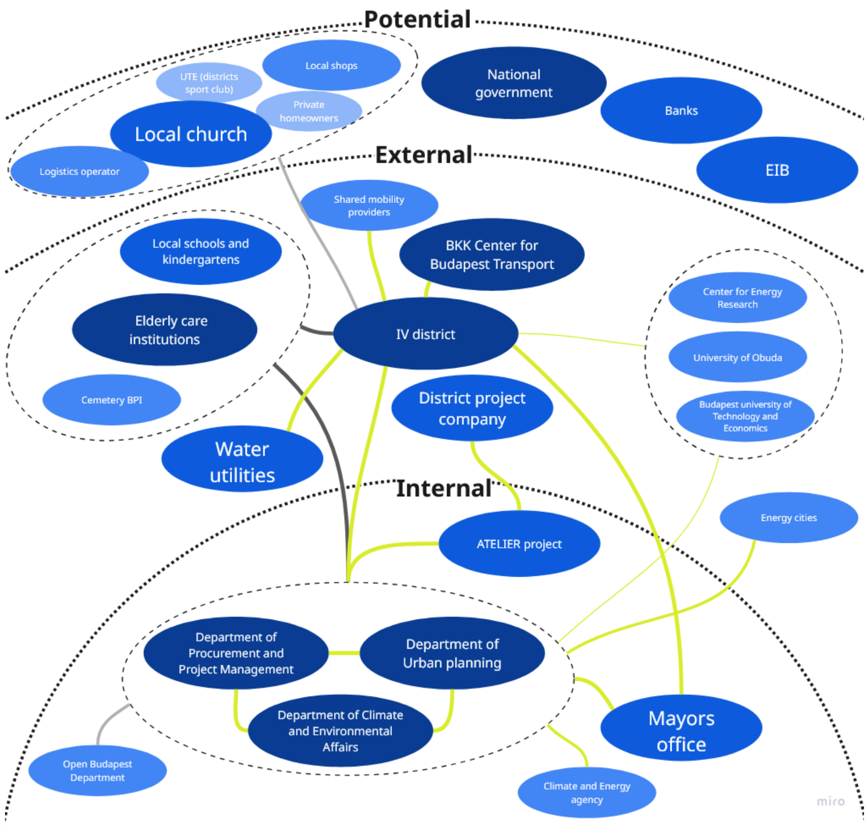
There is strong internal cohesion, solidarity, and a good working relationship among the stakeholders. They can find support from policymakers on the European, metropolitan, and the district levels. ON the other hand, the mission of the energy community to reach energy independence is a conflict of interest with the utility provider. This is especially acute in the light of the goals of ACRED to scale up to the entire complex, which, coupled with further renewable energy and energy efficiency projects, would lead to an existential challenge for Ganz Holding, whose main revenue is operating the complex, and supplying energy for its tenants.

3.2.2. Megyeri, Hungary

1. Table: Expectations of and from the types of actors involved in the Megyeri stakeholder network. Abbrevations are as follows: BUI – building owners, e.g., local church, local shops; MAY – mayor's office; DIS – district municipal organizations; INF – infrastructure operators, including utilities and mobility; RES – research organizations; DPT – metropolitan municipal departments; INV – banks.

	Expectation of the project from the actors			
Expectation of the actors from the project	Participation, political support	Financial support	Knowledge sharing	Communication / coordination
Financial benefits	BUI		BUI	
Knowledge, information, data	MAY, DIS, INF	INV	INF, RES	DPT, DIS
Collaboration, relationships				
Sustainability	INF		INF	DPT
Policy integration				DPT

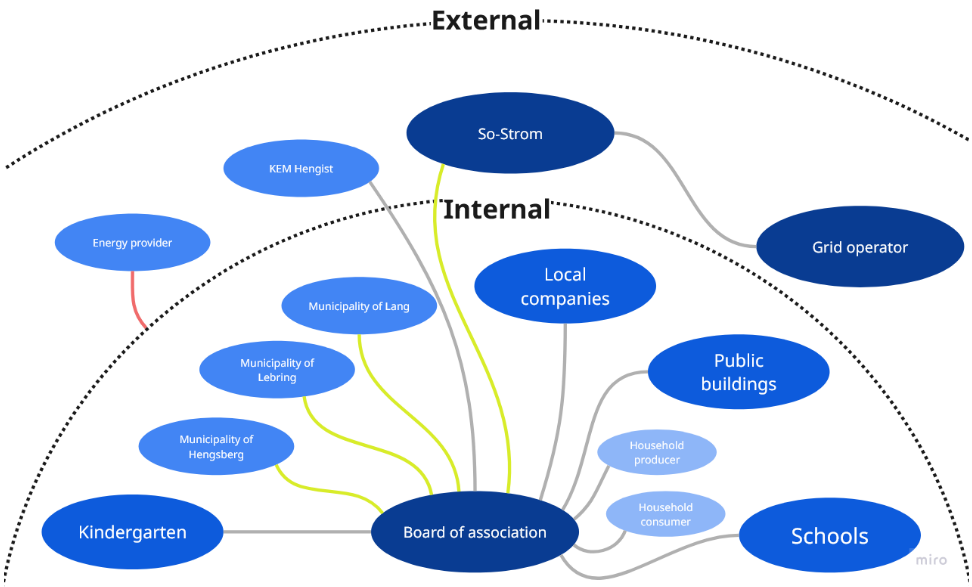
The internal stakeholder network of Megyeri includes the departments involved in PED development, the project team, and the mayor's office. The project team and the civil service is mostly interested in obtaining knowledge how a PED is created within the existing urban fabric, while they manage regulatory and budgetary limitations, alongside expectations from the political level. The latter is represented by the mayor's office, whose political priority is to deliver large-scale, tangible interventions to win over the population for decarbonization, presenting it as a tool to renew the city and improve housing affordability. Through the ATELIER project, three types of external stakeholders are introduced. First, the European Union appears as co-financer, alongside a project consortium with Hungarian and international academic partners and peer cities with their own research and development ambitions. Second, the demonstration area of district 4 brings on relevant departments and the political leadership of the district municipality, whose expectations mirror those at the metropolitan level. Third, different organizations responsible for the assets involved in the project (e.g., cemetery, church), as well as local shops, and private homeowners in its proximity could become future PED members, bringing in a variety of interests, along the lines of value increase, cost reduction, environmental goals, prestige.



4. Figure: Stakeholder relationships and alignment in the Megyeri case. Green line denotes alignment, grey lines neutrality, line weight indicates relationship strength.

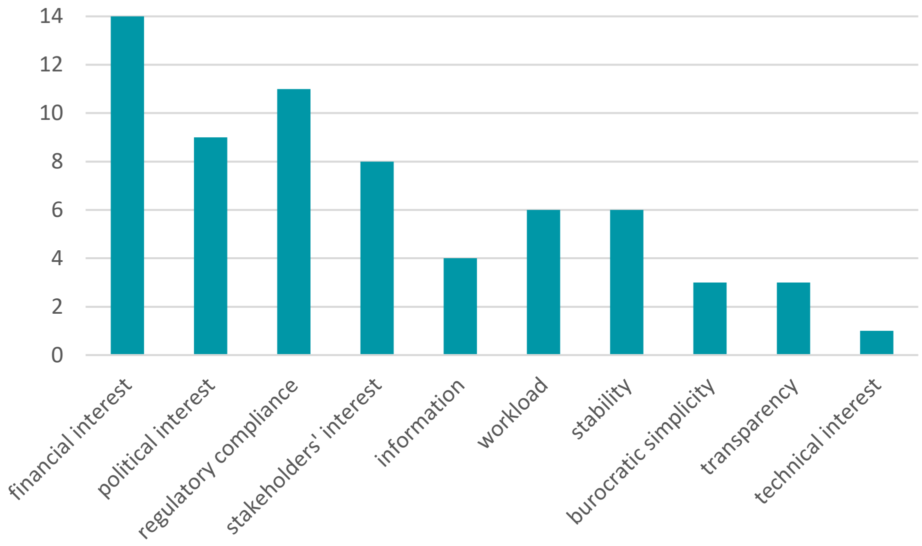
There are no clear opponents identified by the participants. The strongest supporting connections are the ones flowing through the project team, including consortium members, metropolitan and district level departments of the civil service, and municipal companies, such as utility and mobility companies. Organizations managing local assets, including kindergartens, schools, elderly care centres, the church, are strong or medium connections with a neutral disposition. They were selected by municipal departments to participate in the project in which they may or may not see value. Given how both running projects on PED show fewer tangible outputs, compared to the scope of data collection, studies, analyses it involves, it is one of the challenges of the internal stakeholders not to alienate asset managers, and to show up with convincing results to onboard them in PED development.

3.2.3. Lebring and GU Süd, Austria



5. Figure: Stakeholder alignment map of the Lebring case. Green edges denote alignment, grey neutrality, and red opposition.

The Lebring case study involves an energy community of three municipalities, and the following types of units: public buildings, schools, kindergarten, consumer households, prosumer households, and local companies. The GU-Süd is a similar set-up, representing municipalities in the vicinity of Graz, who serve as core members to their energy communities, with household, public building, and SME members. In both cases they are supported mainly by SO-Strom, which provides administration and tax-compliant billing, visualisation and monitoring of energy flows for the community as well as for the members, and standard contracts. SO-Strom also serves as a platform to interactions among the members of the energy community. Externally, the role of the grid operator and the energy provider, who in this case are separate entities, play an important role.



6. Figure: Frequency of mentions of different interests for the stakeholders (total=14).

The municipalities interest lies in strengthening community cohesion, stable and low energy prices, an independence from big energy providers. This puts them at odds with the incumbent providers, who see energy communities as competitors, forcing them to adapt their business models, and grid operators, who are the main bearers of the challenges of grid stabilization. The non-municipal members of the energy community make their decisions based on energy prices and can be both supportive and opposing based on how low and how stable the costs are.

2. Table: Expectations of and from the types of actors involved in the GU-Süd stakeholder network. Abbreviations are as follows: GUS – GU Süd; MUN – municipalities of GU Süd; CON – consumers involved in the energy community; GRI – grid operator.

	Expectation of the project from the actors									
Expectations of the actors from the project	financial expectation	autonomy	political expectation	sustainability	community cohesion	stability	trustworthiness	transparency	expertise	Cooperation
Information	GUS CON	GUS	GUS		GUS	GUS CON	CON	CON	CON	
Leadership	GUS CON	GUS	GUS		GUS	GUS CON	CON	CON	CON	
Transparency	GUS CON	GUS	GUS		GUS	GUS CON	CON	CON	CON	

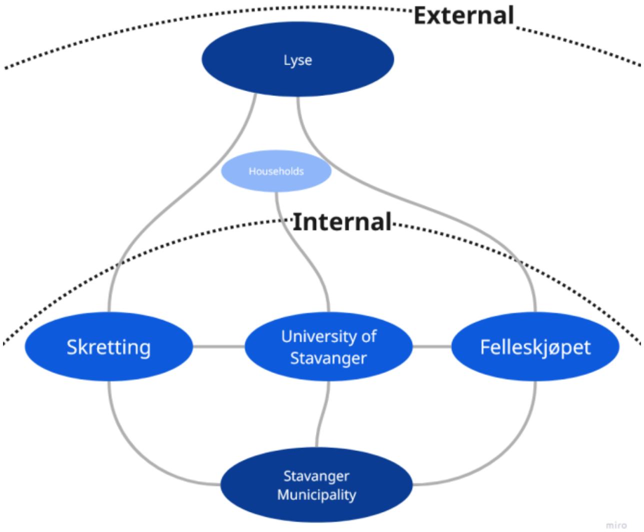
Support	MUN GUS CON	MUN GUS	MUN GUS	MUN GUS		CON	CON	CON	CON	GRI
Sustainability	GUS	GUS	GUS		GUS	GUS				
Operability										GRI
Cooperation	CON					CON	CON	CON	CON	
Expertise	CON					CON	CON	CON	CON	GRI
Efficiency	MUN	MUN	MUN	MUN						

3.2.4. Stavanger, Norway

3. Table: Expectations of and from the types of actors involved in the GU-Süd stakeholder network

		Expectation of the project from the actors				
		Financing	Information	Sustainability	Cooperation	Predictability
Expectations of the actors from the project	Commitment			Stavanger municipality		
	Resource mobilization	University of Stavanger	University of Stavanger	Stavanger municipality, University of Stavanger		
	Effective engagement			Stavanger municipality		
	Sustainability	Skretting	Skretting	Skretting	Felleskjøpet	Lyse

In Stavanger, the stakeholder network is built around the core interaction of selling waste energy from the Felleskjøpet industrial plant to Lyse utility provider company. This in the future could expand with Skretting, another industry actor that could directly take up waste energy for its own production. The other actors, Stavanger municipality and the university, are facilitating this through research, political support, and regulatory alignment. Lyse and the municipality are also joint developers of the energy grid. All actors, bar the municipality, are in it for financial reasons, albeit compliance to strategic goals linked to decarbonization and circularity play a role for most of them – either through political commitment, or the commitment of the shareholders. From the perspective of Lyse, the presence of the municipality is also a guarantee to avoid risks and uncertainties of connecting secondary energy sources to the grid, whereas there is a strong expectation for the university to deliver scientific results.



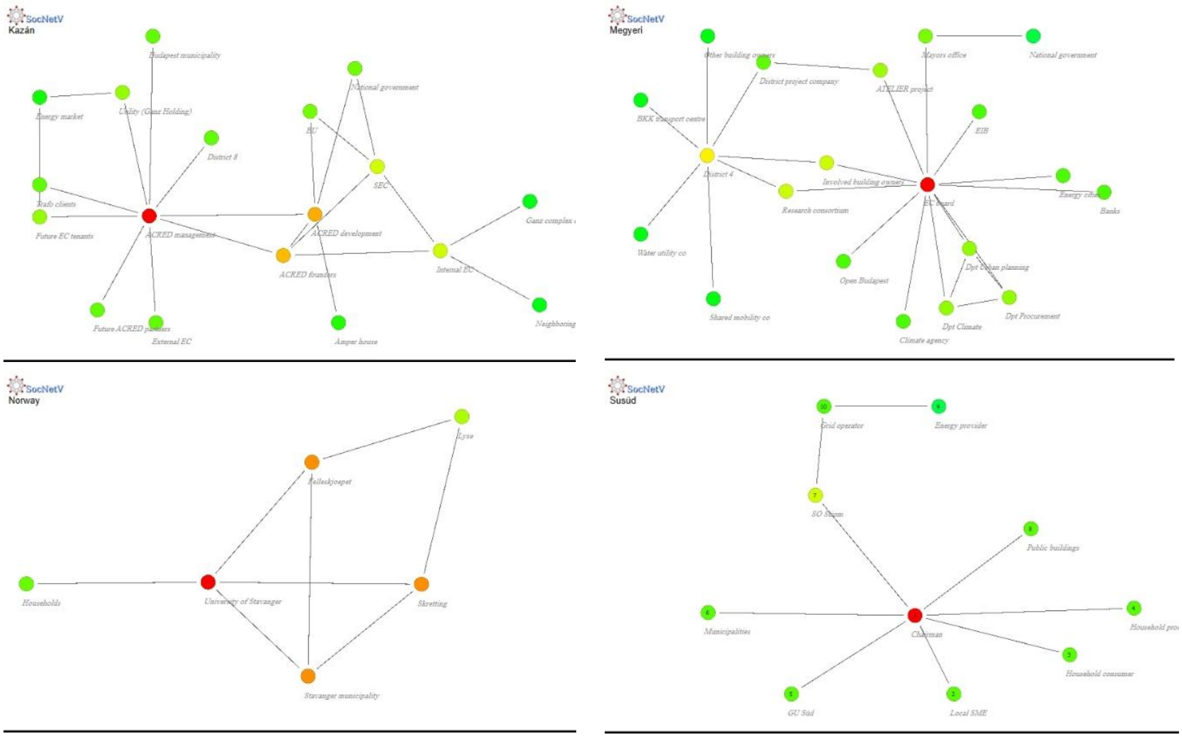
7. Figure: Stakeholder relationships in the Stavanger case. Node size and saturation indicate power.

It is interesting to see the differences between the stakeholders in terms of perceived risks and fears, painting the emotional landscape of the project. The municipality is hard pressed to convince private actors to share the burden of decarbonization as part of the EU cities mission with their own private, but at the same time coordinated investments. Felleskjøpet is reluctant to invest in renewables in general, while Lyse has a lack of trust in this new technological approach.

3.3. Comparison of stakeholder analysis results

The key takeaways from stakeholder analysis concern the size, topology, interest structure, alignment, and emotional structure of the resulting stakeholder networks.

The scale and complexity of the projects vary. At one end, the Stavanger case is minimalistic, focusing only on the key actors needed to facilitate the transaction of secondary energy between the grid operators and the industrial plant. At the other end, the Megyeri case involves two levels of urban governance, with multiple departments at the respective city halls, members of an international research project, a variety of real estate owners, utility companies, and even a list of peripheral, potential supporters around a PED project. While the scale of the problem is one clear reason for the size of the networks, there could also be a geographical factor. The Austrian cases should be larger than the Kazán case, comparable to the Megyeri project, yet they identified less people to work with. The Megyeri case involves the administration of a much larger city, while the Kazán case has a unique, decentralized governance structure. Nevertheless, it is clear that transaction costs associated with communication, coordination, conflict resolution is far more difficult in the Hungarian cases.



8. Figure: Comparison of graph topologies of the cases. Clockwise from top left: Kazán, Megyeri, GU Süd (Lebring is almost identical), Stavanger. Nodes are colored according to power rank centrality, indicating important mediators. Layout is generated using Fruchterman-Reingold model[4], visualizing the different clusters.

Conventionally, one would expect a mediator or a platform to streamline communications, and clustering in larger networks. In the Austrian cases, the respective boards of the energy communities, with technical support from SO-Strom take on this role, holding most of the links in their networks. In the Kazán case, this is served by various subdivisions of ACRED, with a clear division of edges between ACRED management and development branches, creating two largely separated subnetworks. In the Megyeri case, we can observe a platform formed by the involved departments at the metropolitan level, and the district municipality serves as a local mediator to the various actors in the district. Here we have a difference in perspectives compared to the Austrian cases. Because the Budapest case is taken from the vantage point of the metropolitan departments, and the Austrian ones with the municipalities physically involved in the energy communities, a lot of the same type of actors – owners of real estate – are internal for the Austrian cases, but external to the Megyeri case. Reflecting on the earlier point concerning size, this might be a telling insight on how many more relationships need to be managed for those who incubate community energy projects, connecting national and European institutions to local projects.

Managing expectations, closely linked to the varying interests, is key. The networks identified the main conflicts, relationships that cannot be taken for granted, and allies to rely on. The only open conflict

[4] Fruchterman, T. M. J., & Reingold, E. M. (1991). Graph Drawing by Force-Directed Placement. Software: Practice & Experience, 21(11), 1129–1164

identified was a conflict of interest between energy providers and energy communities, in both Austrian cases, and for Kazán. In case the grid operator is a separate entity, this conflict does not include them. The conflict is financial, the energy community is either a client that gradually buys less (Kazán), or an outright competitor on the energy market (Lebring, GU Süd). However, the energy provider Lyse was not marked as adversarial, because in the Norwegian case study, they would be customers. Neutral relationships are typical between consumers and the initiators of the different energy sharing projects. These are typically real estate owners, including residential buildings, local shops, other commercial real estate, industrial plants, and public buildings. They may have an initial sympathy for the community energy project, but this limited patience must be very quickly translated to trust in the long-term viability of the projects. To do so, project initiators must never lose sight of the fact that most members will make financial decisions about joining, investing, participating, supporting a community energy project. Financial interest was top mentioned for stakeholders in all but the Megyeri case, where the abundance of public institutions and technical and scientific partners tilted the scale slightly towards gaining knowledge and experience. It is not insignificant, particularly with public sector-driven projects, to score political points, and in favorable regulatory contexts, there is also healthy pressure to comply with regulations favoring decarbonized, decentralized energy systems.

4. Table: Share of stakeholders associated with different incentive categories across all cases.

Incentives	Kazán	Megyeri	Lebring	GU Süd	Stavanger
	HU	HU	AT	AT	NO
Financial interest	63%	39%	100%	80%	80%
Political interest/strategy	44%	36%	64%	10%	40%
Regulatory compliance	0%	21%	79%	50%	60%
Experience & knowledge	0%	43%	36%	20%	0%
Stake/shareholders' interests, social benefits	38%	36%	57%	20%	60%
Stability of service	0%	0%	43%	40%	0%
Operational benefits	38%	0%	43%	40%	0%

Besides the incentives, the emotional structure of the stakeholders can make or break a successful partnership. The various perceived risks, fears describe how partners feel about community energy, and eliminating the worst fears are necessary, and not as straightforward as proving that the incentives are there. The highest cited risks, mirroring the incentives, are financial risks, with some more color to the responses. Some partners require co-financing to cover upfront costs. Price and wage pressure, economic uncertainty drive down investment for both residential and commercial actors. Transaction costs associated with administration is a significant deterrent in both Austria and Norway. Finally, novelty is a source of different kinds of risks. In the Austrian cases, stakeholders are concerned with the changing legal landscape, particularly in Norway, it is the lack of experience with a new technology, whereas in Megyeri one of the top contentions are technological risks. Interestingly enough, the Hungarian cases were the only ones where some stakeholders were assigned no risks, which can attributed to a large number of peripheral stakeholders who are very indirectly relevant to the projects.

5. Table: Share of stakeholders associated with different risk categories across all cases.

Perceived risks	Kazán	Megyeri	Lebring	GU Süd	Stavanger
	HU	HU	AT	AT	NO
Financial risks	38%	39%	57%	80%	60%
Political and legal risks	6%	0%	57%	80%	20%
Additional workload	6%	0%	64%	70%	0%
Knowledge/experience gaps	6%	21%	14%	20%	40%
Technological limitations	0%	39%	7%	10%	0%
No risk	44%	39%	0%	0%	0%

4. Causal loop diagrams

4.1. Methodological overview

Causal Loop Diagram (CLD) is a visual tool that helps address complex problems and create strategies to overcome them[5]. The goal of their use in Energy4All is to uncover what are the things that matter, and how they relate to one another, in the context of the innovation they are implementing. Each CLD is developed to give a list of the most important variables and interactions that influence the transferability of the innovation to another context. For the purpose of transferability, CLD ought to be populated with information specific to the replicator context.

The rationale for using CLD as a tool is due to the complexity of the problem space in which Energy4All innovations appear in. These problem spaces are wicked, characterized by no clear answers, changes over time, and high risk of unintended consequences. This requires a holistic approach to understanding problems, and how the elements of the problems relate to each other. Methods of system thinking are developed to do exactly that: identification of system elements, relationships, big picture analyses, and long-term thinking. Causal loop diagram (CLD) is a tool to apply systems thinking on any complex problem (Figure 9). It is a visual aid to see the influencing factors (variables) of the problem and the causal relationship between them. It enables us to integrate the perspectives

[5] Sterman, J. D. (2000). Business Dynamics: Systems Thinking and Modeling for a Complex World. McGraw-Hill/Irwin

of different stakeholders and create a shared understanding of your core problem. It results in action ideas for strategic planning and decision-making.

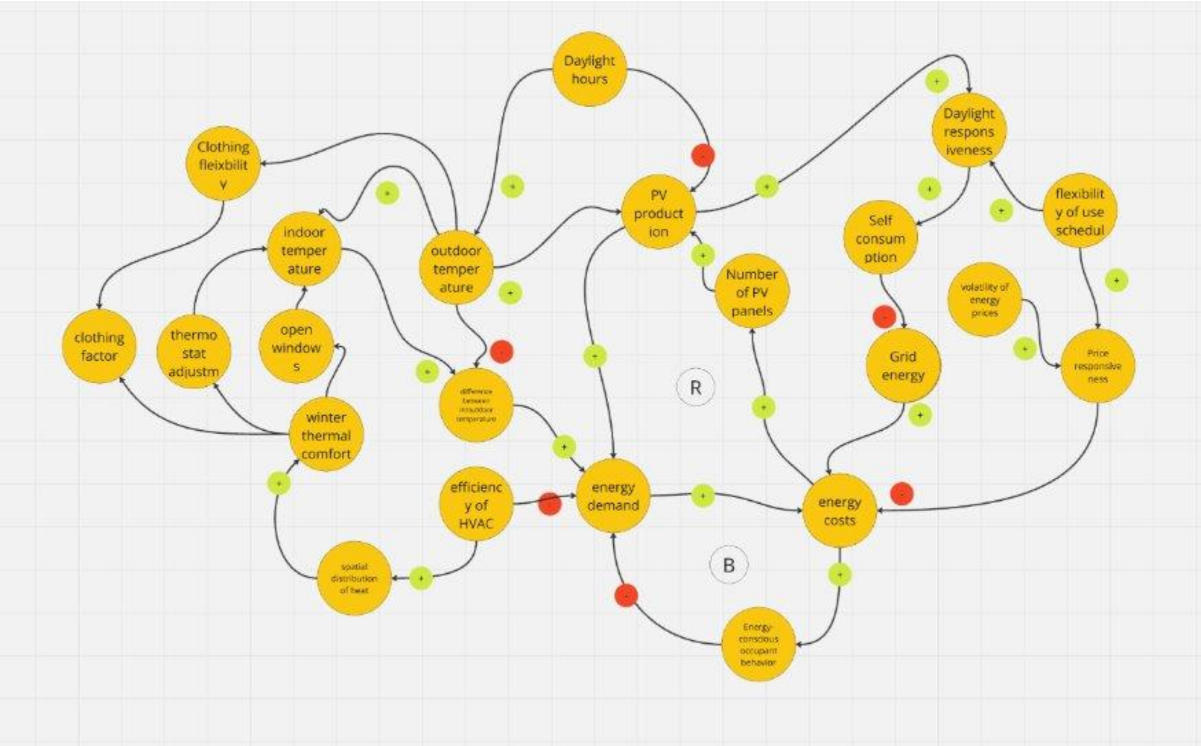


Figure 9 - Example of a Causal Loop Diagram (Source: ABUD)

During T2.2, each local team performed either stakeholder or expert workshops to construct a CLD specific to the underlying problem they intend to solve with their innovation, which was processed by researchers of ABUD. The remainder of this section describes the recommended methodology of data collection and analysis, which can be split into the following steps:

- Definition of the core problem
- Identification of variables of the core problem
- Creating connection circles
- Drawing the CLD
- Creating action ideas

The core problem is a neutral, dynamic (i.e., changing over time) description of a pattern that we want to change. In Energy4All, ABUD recommended using SMART objectives to locate important topics to address (Figure 10). SMART framework is an effective tool to write goals that are clear, attainable, and meaningful. Having clarity with the setting provides the necessary motivation and focus.

Specific	Measurable	Attainable	Realistic	Timely
What do you want to accomplish?	***How will you know when you have accomplished your goal?***	***How can the goal be accomplished?***	***Is the goal realistic and within reach?***	***When will the goal be accomplished?***
-What do I want to accomplish? -Why is this goal important? -Who is involved? -Where is it located? -Which resources or limits are involved?	-How much? -How many? -How will I know when it is accomplished?	-Do I have the resources and capabilities to achieve the goal? If not, what am I missing? -Have others done it successfully before?	-Is the goal realistic and within reach? -Is the goal reachable, given the time and resources? -Are you able to commit to achieving the goal?	-When? -What can I do six months from now? -What can I do six weeks from now? -What can I do today?

Figure 10 - Driving questions to use SMART objectives as a framework (Source: ABUD)

The next step is identifying variables. These variables should be potential factors influencing the core problem (barriers and enablers), expressed as nouns or noun phrases, neutral (“user fees” instead of “high user fees”), named very clearly in normal (positive) sense of direction (“motivation” instead of “demotivation”). During the workshop, facilitators are advised to conduct free brainstorming with participants, writing down every idea on post-its (Figure 11), clarifying what each idea means in front of the whole group. Then, it falls to the cooperation of the facilitators and participants to narrow down the list to 10-15 items. The facilitators should propose merging overlapping variables, collapsing variables to level out the detailedness, and eliminating variables more clearly dissociated from the rest. If needed, the group can vote on ranking the variables to land at the desired target.

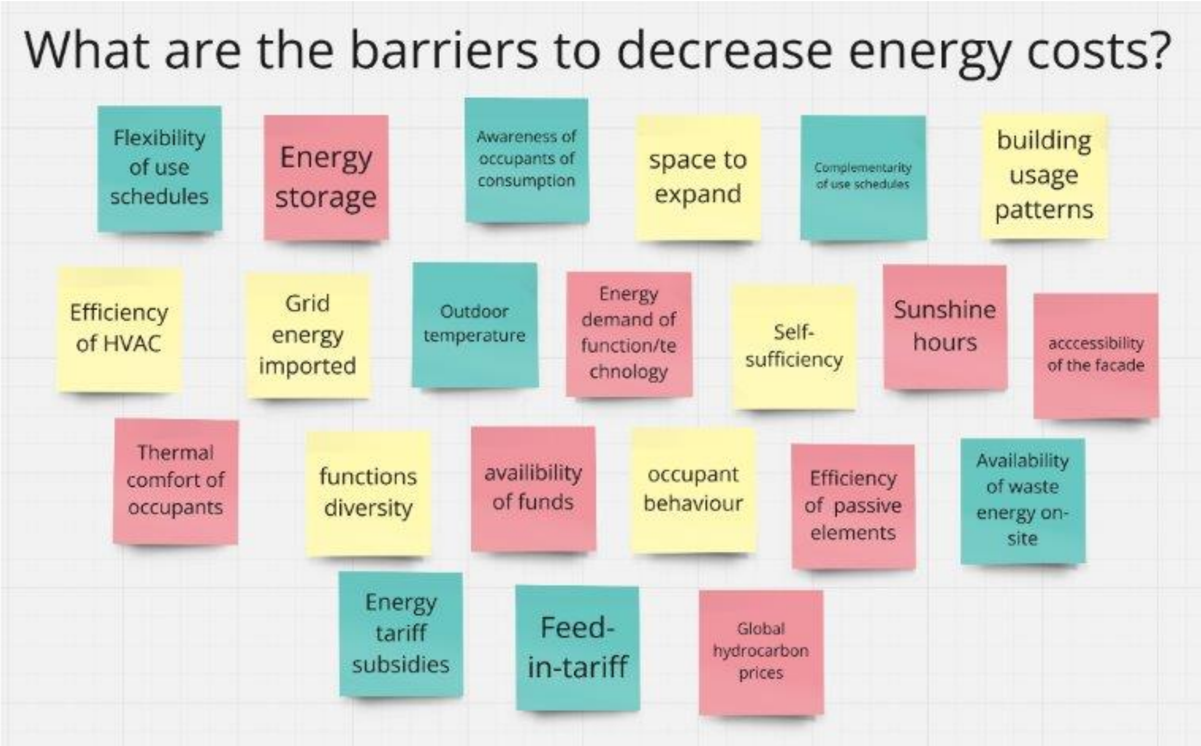


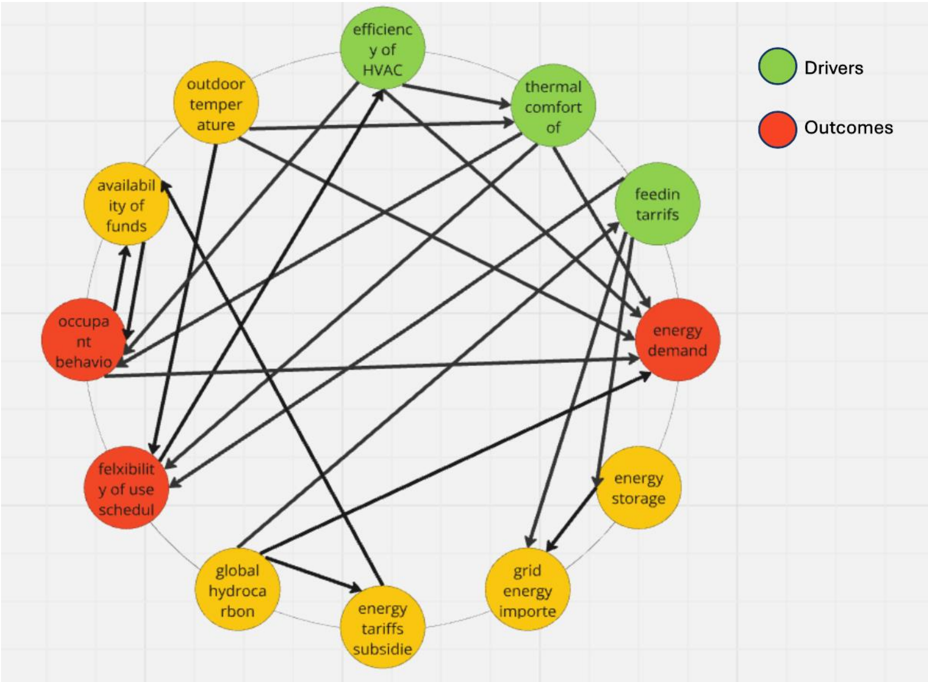
Figure 11 - Collecting variables (Source: ABUD)

Step 3 is to explore all possible relationships amongst the variables. Using a connection circle encourages participants to think in multiple directions, avoids recreating preexisting theories about how the system functions, allows key issues to emerge organically, and root causes to be found even in the absence of hard data. Steps to construct a Connection Circle:

1. Write a big circle and write the top 10-15 variables of the previous task on a perimeter of it.
2. Pick one of the variables to start with and think about its relationship with each of the other variables in your circle. Consider relationships in pairs (you do not have to find a relationship between each pair).
3. Use an "influence" arrow to connect related elements.
4. The arrows should be drawn from the element that influences the one influenced.
5. If two elements influence each other, the arrow should be drawn to reflect the stronger influence. Arrows can only be drawn in one direction.
6. The relationship should be a direct relationship and not via another variable.
7. When you are thinking about how one variable relates to another, be sure to consider short term effects, long term effects, and unintended consequences. Try your best to abandon your mental model and think about associations you might not have initially identified. Where base your decision on existing evidence, or consensus amongst experts and be aware of your own assumptions.

Once all the possible relationships amongst the variables are examined, it is possible to identify the drivers and outcomes in the system (Figure 12).

1. Count the arrows. Look at each variable and count how many arrows you have coming into that variable and how many you have going out.
2. Variables with more arrows coming in than out are outcomes; those with more arrows going out are drivers.
3. The elements with the most outgoing arrows will be "root causes" or "drivers."
4. The ones with the most incoming arrows will be key outcomes or results.



5. *Figure 12 - Connection circle with drivers and enablers (Source: ABUD)*

Step 4 is to create causal loop diagrams (see for example Figure 13). To do so, nodes from the previous step would have to be rearranged, drivers and outcomes gathered on opposite sides of the diagram. When adding interim variables, it will likely be necessary to expand the model with new variables. This is especially true for cases where an interim variable has an incoming edge from a driver node that may influence the variable, but not significantly, which could make the visual presentation overestimate some causal pathways on unweighted graphs (which a CLD is). Then, each edge must be classified based on polarity – positive if the nodes go in the same direction, negative if they go in opposite directions. If this is hard to do, probably another interim variable is required. Then edges must be marked where there is a significant time delay, which could cause an imbalance in the system. Finally, feedback loops must be identified for causal chains that end in the same node as they started. Loops are also marked based on their polarity: if there is an odd number of negative edges, the loop is balancing, otherwise it is reinforcing.

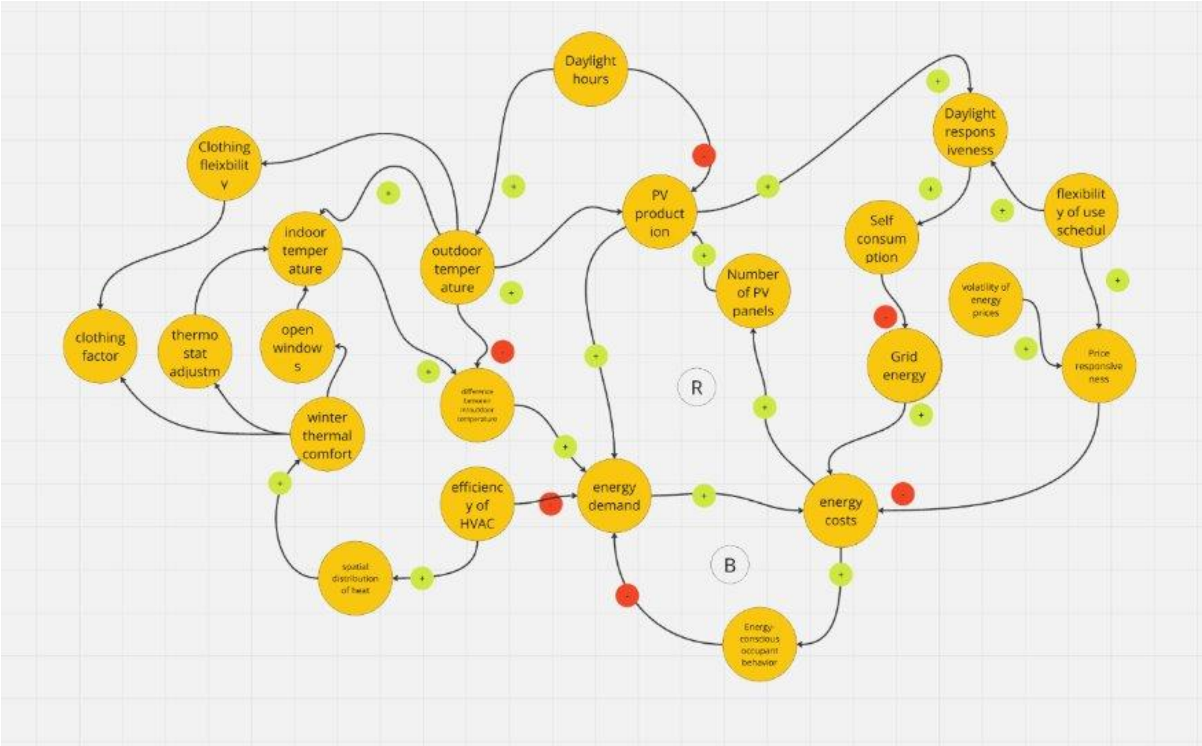
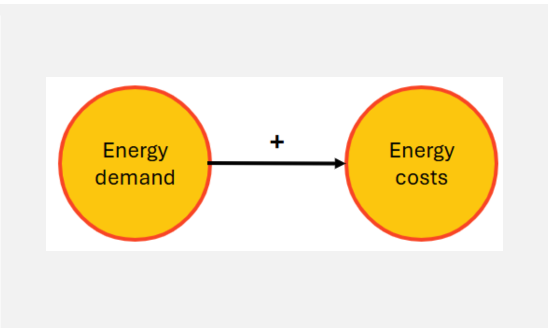
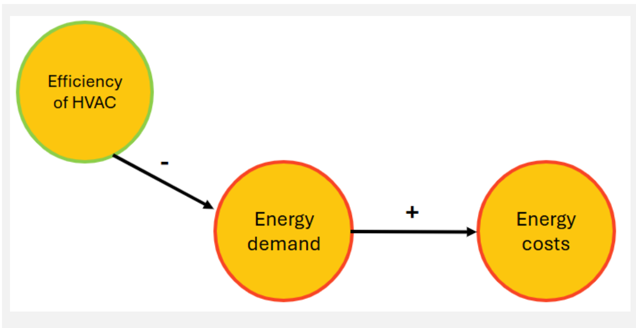


Figure 13 - Causal Loop Diagram result (Source: ABUD)

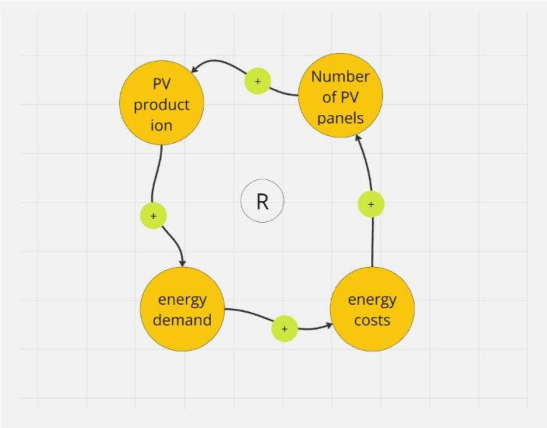
See the panel below for a more detailed description of CLD elements. Some of the elements may be added during the workshop, but full revision by an expert team is necessary after the workshop.



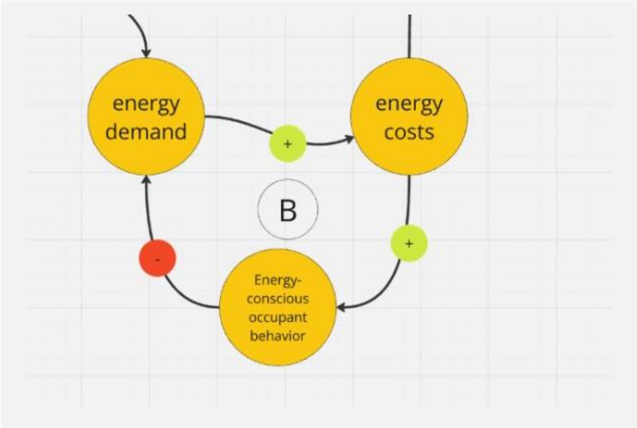


Positive polarity is when the target variable moves in the same direction as the source variable.

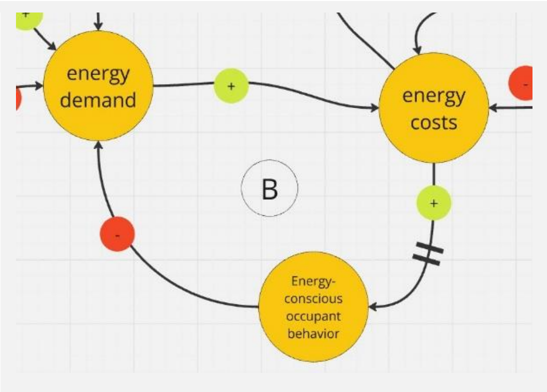
Negative polarity is when the target variable moves in the opposite direction as the source variable.



A reinforcing feedback loop is when the negative polarities are even (including zero). Such loops cause the variables in them to increase continuously without any sustaining an intervention.



A balancing feedback loop is when the number of negative polarities is odd. Such loops dampen the effect of interventions, forcing the system towards a state of equilibrium.



Time delays denote if there is an onset in the effect of the source variable.

The final step is to identify potential actions to intervene. In a workshop format, this should be done as an open, reflective discussion, guided by the facilitators. Participants should be advised to identify leverage points before recommending actions. A leverage point is a place in the system's structure when an intervention can be applied. A low leverage point is one where a small level of intervention or change force results in a small change in the behavior of the system. In contrast a high leverage point is one where a small level of intervention/ change force causes a large change in the system's behavior. The leverage points can help steer the discussion to effective interventions strategies (6. Table).

6. Table: Intervention strategies in CLD, based on de Pinho[6]

System dynamic	Intervention
Stagnant, stalled systems	Look for constraints, intervene on balancing feedback loops, find causal pathways with less delays or alternative paths.
Vicious cycles (reinforcing feedback loops with adverse outcomes)	Identify brakes, intervention points to exit such loops.
Virtuous cycles (reinforcing feedback loops with desired outcomes)	Find places to intervene to either kickstart or accelerate the cycle.
Multiple loops	Find variables in the strongest feedback structures.
All edges	Review the consequences of strengthening or dampening them.

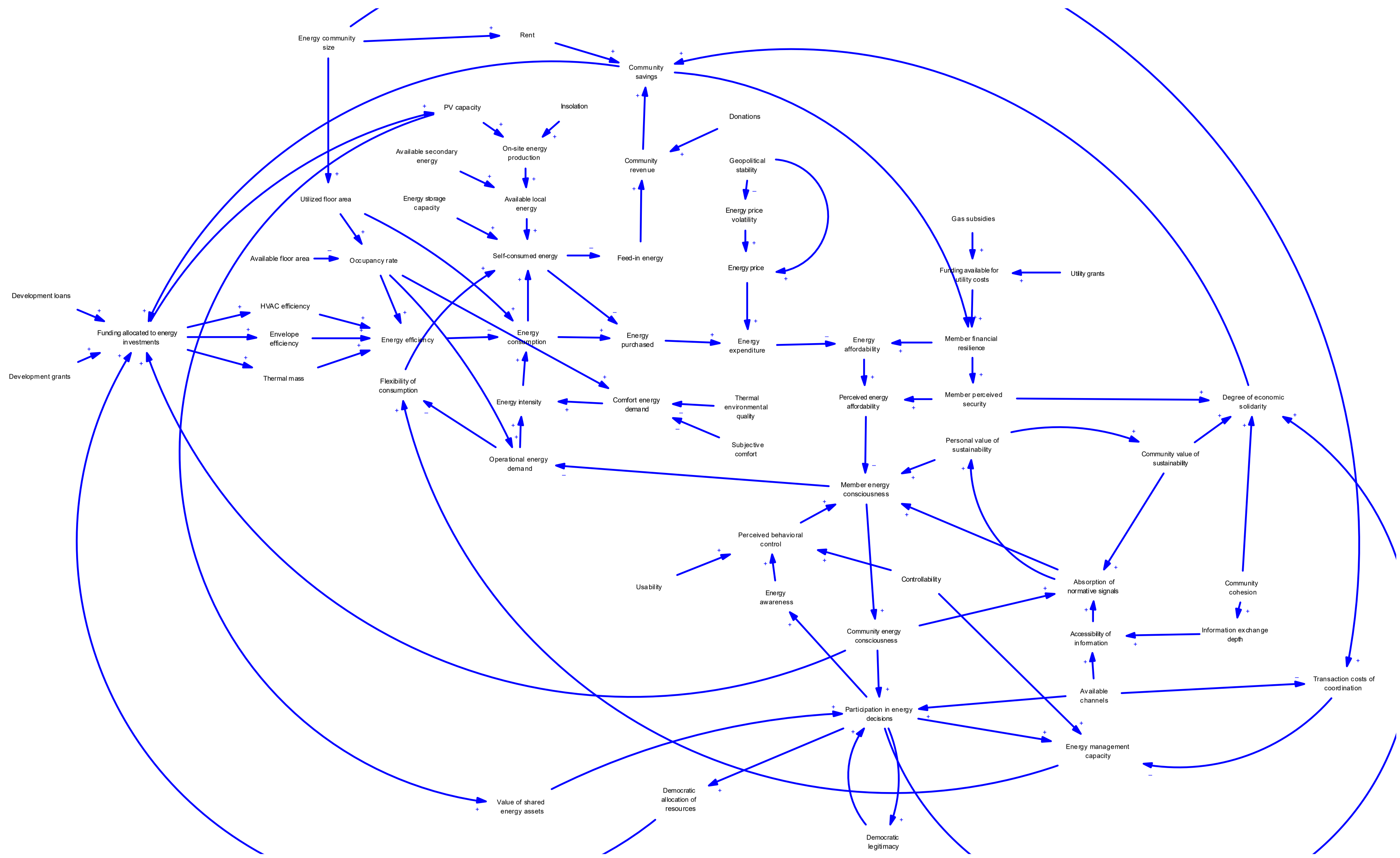
4.2. Pilot Case Studies – Casual Loop Diagrams

4.2.1. Kazán community, Hungary

The Kazán case study was focusing on energy expenditure. At the same time, energy expenditure does not appear as clear outcome by reading the CLD. In fact, none of the variables are clear outcomes, since neither of the nodes stand out as targets. Similarly, there are no clear drivers, as the CLD suggests the most upstream nodes represent the edges of subject matter knowledge, rather than a main driving force. The model clearly splits into a technical and a social cluster, with some interactions between the two. Some nodes with a larger than average degree serve as concentration points for multiple causal chains that can be highlighted to get a simplified picture. Energy consumption integrates chains from various drivers of energy demand, on-site energy production, and energy efficiency. Energy consciousness captures behavioural drivers and social interactions and links it to energy demand. Participation in energy-related decisions funnels all social drivers, variables related to the self-governance of the community, and to finance. The most prominent interlinkages between the technical and social side include the influence of adaptive occupant behaviour on energy demand, community-level engagement and strategies related to investing in energy efficiency, and different pathways allowing communities to manage their energy consumption more flexibly, relying less on grid energy. Due to the size of the model, there are 17 independent loops in it, the most prominent ones are as follows. Participants identified economic reinforcing feedback loops of creating a rolling fund that uses savings and revenue from energy investments to finance new

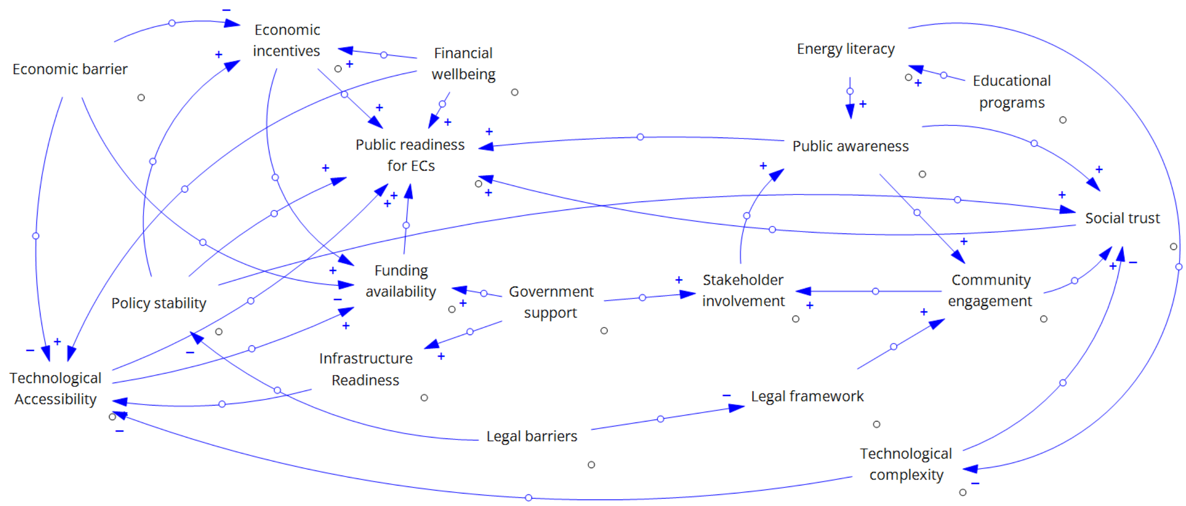
[6] De Pinho, Helen (2015) Participants Guidelines. Systems Tools for Complex Health Systems: A Guide to Creating Causal Loop Diagrams. Columbia University. New York City. Retrieved from: cld_course_participant_manual.pdf

ones. This over time increases asset value, participation, potentially either or both savings and renewable capacities. Multiple reinforcing feedback loops were identified relating to behaviour: both through social interactions and through participation in energy related decisions, energy consciousness and a personal value of sustainability can be increased, leading to more participation, higher chances of sharing these signals, and higher perceived behavioural control, restarting the loop. There is a balancing feedback loop at the core of the model, which describes increasing energy affordability driving down interest in energy by the members, decreasing investment into lowering consumption, or running into rebound effects, which returns to energy affordability. As member energy consciousness captures other dynamics as well, these would be crucial to avoid a premature departure from decarbonization. However, these signals are important to prioritize investments in a solidarity economy based not only on energy aspects. This is especially important since economic solidarity is also part of a balancing feedback loop, which makes energy less of a driver for solidarity, if there is no perception of energy poverty. There is also an economic trade-off between self-consumption and feed-in of produced energy. A balancing loop highlights that higher flexibility gained from investment in production, mediated by more attention of the members to energy affairs, can translate to lower revenue from feed-in. This is not an issue in Hungary where feed-in tariffs are remarkably low, but could hit cash flows where the energy community is also a seller of energy.



14. Figure: CLD of the Kazán case study

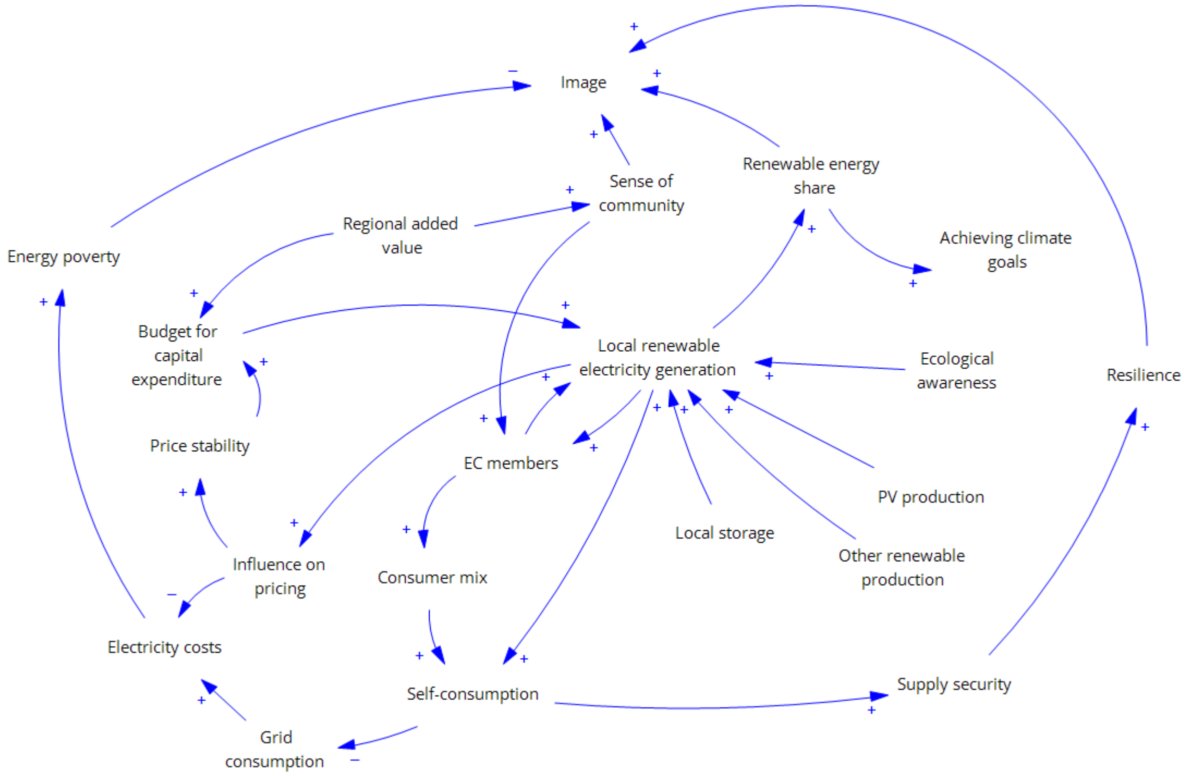
4.2.2. Megyeri positive energy district, Hungary



15. Figure: CLD of the Megyeri PED case study

The focus of the Megyeri case study was centred around creating the first functional positive energy district in Hungary. At first glance, the system built by the participants is an attempt to be holistic, at the cost of masking complexity behind some generic nodes, e.g., "economic barrier". The main outcome of the described model is public readiness for energy communities, and the entire model describes causal pathways towards this single objective. Interestingly, only three of the neighbouring nodes funnel in all the other factors within the system: funding availability, technological accessibility, and social trust. The independent drivers are economic barriers, legal barriers, government support, educational programs, and financial wellbeing, although it was made clear by the participants that many of the in-between nodes only loosely depend on some of their parents. For example, educational programs influence technological complexity via energy literacy, but it is not the most important pathway influencing it. These distinct drivers divide the system into an economic-technological, and a societal-governance cluster, with some interactions between the two. Economic barriers influence most of the causal chains on the former, it can decrease the availability of incentives, sources of investment, and also access of technology. On the other side, both government support, and education has important roles in raising awareness, engaging communities, providing pathways for participation, and most importantly increasing trust. The system is mostly cascading, there is one reinforcing feedback loop: community engagement driving up stakeholder involvement, which in turn raises public awareness, thus unlocking a higher percentage of the community to be engaged.

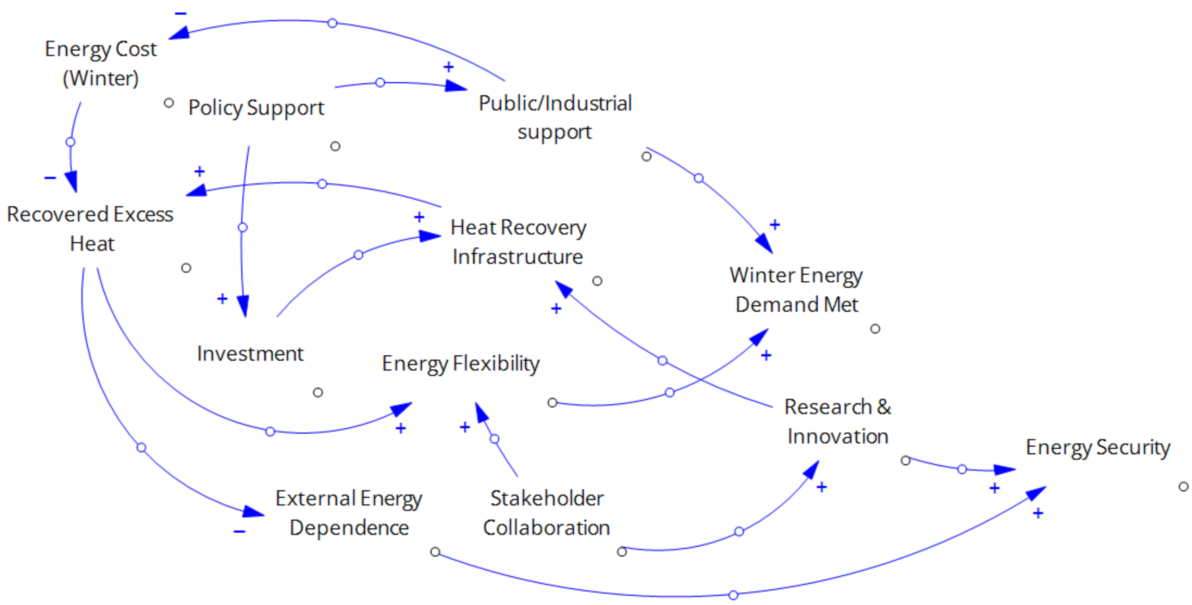
4.2.3. Vienna, Austria



16. Figure: CLD of the Vienna case study

The system describes the dynamics surrounding local renewable electricity generation. It is both the main outcome, and a driving force of several co-impacts. The participants tended towards describing socioeconomic dynamics in much greater detail than technical ones. PV production, local storage, and other renewables are direct drivers of local electricity generation, but their interlinkages with the socioeconomic factors are not explored. The system demonstrates the co-benefits of higher local production, including resilience, reduced costs, thus energy poverty, contributing to a sense of community and better self-image of communities, alongside achieving climate goals. Between production and image, there are six distinct causal chains. The participants also identified two reinforcing feedback loops. First, increased production may attract more members to the community, who in turn drive up production. Second, an increased share of local renewable production increases the role of renewables on the price market, acting as a price stabilizing force, which could unlock more investment in renewable energy generation.

4.2.4. Stavanger, Norway



17. Figure: CLD of the Stavanger case study

The underlying issue explored in Stavanger was the utilization of waste (heat) energy from an industrial plant. The two main outcomes of the system are energy security, and winter energy demand met through recovered heat. From the perspective of the underlying issue, energy security is a long-term impact, while winter energy demand is the immediate outcome. The two main drivers are policy support and stakeholder collaboration. Policy support influences the main outcome through three distinct causal chains. Beneficial pathways include a direct influence on asset owners to participate in demand-side response management, or public sector co-financing or incentivizing investments in heat recovery infrastructure, both of which increase the share of energy demand met through heat recovery. Increased stakeholder collaboration can also increase participation in demand-side response management. The two main pathways towards more energy sharing are therefore driven either by participation or material conditions. Conversely, policies can also drive down energy prices, e.g., with fuel subsidies, which in turn lowers the returns on investing in energy flexibility, disincentivizing energy sharing. This is a third pathway, where the driving force is market design. The local workshop participants did not identify a feedback loop.

5. Comparison of the system mapping results

All case studies explored systems connected to the main overarching theme of peer energy sharing, either in the context of energy communities (Kazán, Megyeri, Vienna), or a transactional (Oslo). At the same time, each case study had a very different underlying problem, which reflected in the main outcome of the system models (7. Table). Given that neither of the participants were told what to focus on, this reinforces the notion that community energy and energy sharing in general intersects with a variety of perspectives, interests, and individual objectives. In the case of Kazán, where most participants were community members of a locally quite disruptive model – solidarity economy – the focus was on maximizing the economic potential of the energy transition, and to see what benefits they can provide for members. In the Megyeri and Vienna cases, the participants were representatives of local governments, each focusing on their immediate, and specific policy targets. For Megyeri, it was mobilizing households for their PED project, for Vienna, meeting renewable energy production quotas. In the Oslo case, a mix of industrial and academic participants gravitated to the very practical question of the potential of heat recovery and mapping out risks and synergies for it. The motivations also influenced the structure of the causal network. Where the outcome indicators more clearly matched the main objectives of the participants, there was a tendency to list variables that directly or indirectly influence it. This resulted in cascading networks with fewer or even no (Oslo) feedback loops. In contrast, discussions during the Kazán workshop went further away from the initial problem (energy expenditure), which does not even appear as a clear outcome on the model, which on the other hand identified the most variables and most independent feedback loops.

7. Table: Comparison of CLDs in different case studies

Case study	Main outcome	Dominant topology	Clusters
Kazán, HU	Energy expenditure	Looping	Social, technical
Megyeri, HU	Public readiness for energy communities	Cascading	Techno-economic, social
Vienna, AT	Local renewable electricity generation	Cascading	Energy, image
Oslo, NO	Winter energy demand met by heat recovery	Cascading	No clustering

In all cases, there was a healthy mix of variables covering a wide range of disciplines, more specifically technical variables related to buildings, energy consumption, renewable energy, economic variables about energy markets, budgeting, and investments, variables related to occupant behavior and social interactions, and to policy and governance. This reinforces the sociotechnical nature of the energy transition, particularly in the context of energy sharing. Both the Austrian an Hungarian case studies highlighted the importance of not only individual behavior, but interpersonal and community dynamics, offering several new variables, e.g., normative signals, which are not typically found in behavioral models on energy. This is since such models tend to treat building occupants as adaptive agents responding, through an internal logic, to comfort cues, through the affordances of buildings and their management systems. The key contribution of this study is to show that social interactions are equally, if not more important sources of cues, and these translate to hard economic and technical outcomes as well, particularly through pathways linked to energy flexibility, energy conscious behavior, participation and investment in energy transition.

6. Conclusion

The systems mapping results presented in this report demonstrate that energy-sharing initiatives and energy communities function as complex socio-technical systems rather than as standalone technical or market interventions. Successful replication in new contexts therefore depends on policymakers' ability to recognize, anticipate, and actively shape the system dynamics that enable or constrain these initiatives. The following recommendations distil cross-case insights into actionable guidance for policymakers seeking to support the transfer, scaling, or replication of energy-sharing models.

1. Treat energy communities as socio-technical systems, not technical projects.

Across all pilot cases, outcomes emerged from interactions between social actors, governance arrangements, behavioral dynamics, market incentives, and technical infrastructures. Policies that focus narrowly on technology deployment or financial incentives risk activating balancing feedback loops—such as reduced engagement once affordability improves—without sustaining long-term participation. Policymakers should therefore adopt integrated policy packages that simultaneously address regulation, social engagement, institutional coordination, and technical feasibility.

2. Actively shape stakeholder configurations and power relations.

Stakeholder mapping revealed that replication success depends on how roles, interests, and influence are distributed within the system. Energy communities require trusted intermediaries or platforms (e.g. municipal bodies, community organizations, service providers) to reduce coordination costs and mediate conflicts, particularly between communities and incumbent energy providers. Policymakers should explicitly support such intermediary roles through mandates, funding, or regulatory recognition, rather than assuming that coordination will self-organize.

3. Align incentives to avoid structural conflicts with incumbent actors.

In several cases, energy communities were perceived as competitors by energy suppliers, creating systemic resistance. Where unresolved, such conflicts can block scaling despite strong community engagement. Policymakers should design regulatory frameworks that either realign incumbent incentives (e.g. through service-based remuneration, flexibility markets) or clearly separate competitive and cooperative functions within the energy system.

4. Address trust, expectations, and perceived risks as core policy variables.

Causal loop diagrams consistently highlighted trust, perceived financial risk, and expectations of stability as key mediating variables between policy interventions and outcomes. These variables often introduce time delays that weaken policy impact if not acknowledged. Policymakers should therefore complement financial instruments with measures that reduce uncertainty—such as long-term regulatory stability, standardized contracts, and public guarantees—while investing in transparent communication and participatory processes.

5. Support reinforcing feedback loops while managing balancing effects.

Successful cases identified virtuous cycles linking participation, investment, social learning, and energy performance. However, balancing loops—such as reduced motivation once energy costs fall—can stall transitions if left unmanaged. Policymakers should monitor these dynamics and intervene at leverage points, for example by linking affordability gains to reinvestment mechanisms, community funds, or adaptive governance structures that sustain engagement over time.

6. Allow contextual flexibility while safeguarding core system functions.

While the pilots differed significantly in scale, governance, and technological focus, common functional elements emerged: mechanisms for participation, platforms for coordination, pathways for investment, and institutional support. Replication strategies should therefore avoid rigid models and instead focus on preserving these core functions while allowing local adaptation to institutional, cultural, and economic conditions.

7. Use systems mapping as a standard policy design and evaluation tool.

Finally, this report demonstrates the value of stakeholder mapping and causal loop diagrams as tools for anticipatory governance. Policymakers are encouraged to institutionalize systems mapping in the early phases of policy design and replication planning, using it to identify leverage points, unintended consequences, and context-specific risks before large-scale implementation.

In conclusion, replicating energy-sharing and energy community innovations requires policies that are as systemic as the challenges they address. By engaging with the underlying socio-technical dynamics—rather than only their visible outcomes—policymakers can significantly increase the likelihood that these innovations will deliver durable, scalable, and socially embedded contributions to the energy transition.