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Master Thesis

Citizen-Facing Frontend Representation of Renewable Energy Community Scenarios: Translating Technical Indicators into Benefit Scores

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Abstract

Across Europe, Renewable Energy Communities (RECs) are increasingly used to organise renewable energy production and sharing at the local level, with citizens involved in these activities. Many existing REC geoportals and dashboards can already display technical outputs such as installed capacity, renewable energy production, self-consumption rate, self-sufficiency rate, energy surplus, and emission reductions. These outputs are valuable for planners and technical stakeholders, but they are still not sufficiently effective for ordinary residents. Residents need to understand what local energy conditions mean, how they might participate in a REC, and which form of participation best fits their own circumstances.

This thesis investigates how technical REC indicators can be adapted for a citizen-facing platform. The analysis began with the 58 indicators proposed by Mutani et al. (2020). Each indicator was checked against the datasets, SQL scripts, and official sources used in the study to establish whether it could currently be calculated. Its relevance to citizens and suitability for frontend presentation were then reviewed. Indicators that could not be supported by the available data or presented clearly were not carried forward into the prototype. The remaining indicators were assigned to Economic Benefit, Local Energy Benefit, or Environmental Benefit.

The prototype is organised into five modules: Local Energy Story, My Role in the REC, Benefit Explorer, Scenario Explorer, and Preferences and Community Signals. Users first review the local energy baseline and identify a possible participation role. They can then examine the benefits linked to that role, compare the available scenarios, and adjust the final ranking according to their preferences. At the interface level, the prototype connects the earlier indicator assessment and scoring rules with the way the results are presented to users. The main contribution of the thesis is to show how REC indicators can be selected and transformed into platform outputs that residents and potential REC participants can understand, compare, and use to form an initial judgement.

Keywords: Renewable Energy Communities; citizen-facing platform; indicator translation; benefit score; scenario ranking; energy community dashboard

Chapter 1. Introduction

1.1 Research Background

The low-carbon transition of the European energy system is shifting energy production and governance away from a traditionally centralized model toward more local, distributed, and participatory structures. Renewable Energy Communities (RECs) provide an organisational structure for this shift. The European Union's renewable energy framework allows citizens to participate alongside municipalities, small and medium-sized enterprises, and other local actors. Within a RECs, these actors can jointly produce and share renewable energy, consume it, or provide storage capacity.Within a RECs, residents can assume roles beyond electricity consumption. Some join as members or prosumers. Others mainly receive shared benefits, while participation in local decisions depends on the community’ s governance structure.

In Italy, RECs development is shaped by the national policy and incentive framework, including the PNIEC and the 2023 CACER Decree. These instruments address RECs, collective self-consumption, and distributed renewable energy in relation to energy security and the low-carbon transition. Within this framework, a RECs combines energy technologies with local cooperation among citizens, municipalities, private actors, and public entities.

GIS datasets, urban building energy models, and scenario tools can describe local energy systems in considerable detail. RECs geoportals often report renewable energy production together with self-consumption, self-sufficiency, surplus energy, and emission reductions. These outputs support planners, local authorities, and technical specialists. Residents usually need further explanation of how the reported values relate to local energy conditions and possible forms of participation. This thesis therefore focuses on how RECs technical indicators can be converted into a citizen-facing platform structure that supports users in understanding local energy conditions and comparing different scenarios.

1.2 Problem Statement

Existing RECs geoportals, dashboards, and simulation tools have made substantial progress in spatial analysis, renewable energy assessment, techno-economic calculation, and scenario comparison. However, their outputs are often still difficult for ordinary citizens to interpret directly. GIS datasets, urban building energy models, and scenario tools can describe local energy systems in considerable detail. RECs geoportals often report renewable energy production together with self-consumption, self-sufficiency, surplus energy, and emission reductions. These outputs support planners, local authorities, and technical specialists. Residents usually need further explanation of how the reported values relate to local energy conditions and possible forms of participation.

Technical detail and public readability are handled unevenly across existing platforms. Some provide extensive spatial and energy data, but interpreting the outputs often requires knowledge of energy indicators or GIS. Platforms designed for a wider public tend to simplify the information. In doing so, they may omit the links between the displayed results, RECs indicator frameworks, spatial constraints, and local socio-economic conditions. Citizens are therefore often presented either with technical outputs that are difficult to interpret or with simplified information that offers limited support for comparing participation options.

The study checks which REC indicators are relevant to citizens and can be supported by the available datasets and SQL scripts. Indicators retained after this screening are translated into citizen-facing outputs. Within the prototype, they are used to explain potential benefits, identify participation pathways, and compare REC scenarios. The platform prototype is therefore positioned as an interface layer that helps residents read local energy information and form an initial judgement about possible forms of REC participation.

1.3 Research Aim and Objectives

This thesis develops a citizen-facing Renewable Energy Community prototype focused on the translation between REC technical indicators and public information. REC indicators are reorganized as platform outputs that help residents understand local energy conditions, identify possible participation roles, and compare different REC scenarios in terms of economic, local energy, and environmental benefits.

The research follows an indicator selection to interface translation sequence. First, the REC indicators proposed by Mutani et al. (2020) are used to establish the source indicator list. The data availability and current calculability of each indicator are then assessed using the datasets, scripts, and official sources available for this thesis. Next, the indicators are mapped to different stakeholder groups in order to identify those most relevant to citizens. After screening, the selected indicators are reorganized into a benefit-oriented scoring structure and embedded in the platform prototype to support local energy baseline reading, role identification, benefit exploration, scenario comparison, and preference-based ranking.

1.4 Research Questions

1. In the context of a citizen-facing platform, which REC indicators are most relevant to citizens?

2. Based on the available data and scripts, which of these indicators can currently be calculated or presented?

3. How can these indicators be translated into benefit scores and interactive scenario comparisons within a platform prototype?

Chapter 2. Literature Review

2.1 Renewable Energy Communities and Citizen Participation

RECs are an important organizational form in the shift of the European energy system from centralized structures toward local, distributed, and participatory arrangements. They are not simply a combination of renewable energy devices, but an institutional arrangement that connects energy production, consumption, storage, sharing, and local governance. The 2019 Clean Energy Package and the revised Renewable Energy Directive (RED II) established the EU framework within which RECs are defined and governed. Lowitzsch et al. (2020) explain that RED II gives RECs a formal definition and sets out arrangements for community governance. It also recognises energy sharing among members. Under this framework, a REC is a locally organised energy entity whose operation depends on rules for membership, control, and decision-making as well as on energy technologies.

This institutional framework changes the role assigned to citizens in local energy systems. Under conventional arrangements, households mainly purchase and use electricity supplied by external providers. RECs and peer-to-peer energy communities offer other forms of involvement. A household may remain a consumer or become a prosumer, while also taking part in a wider community arrangement. D'Alpaos and Andreolli (2021) examine cooperation among consumers, prosumers, local authorities, and energy utilities, linking this cooperation to economic, environmental, and social benefits. Ahmed et al. (2024) also understand RECs as community-based energy systems in which local renewable energy use, energy independence, citizen engagement, and community benefits are closely connected.

Citizen participation is therefore a key aspect that distinguishes RECs from ordinary distributed renewable energy projects. Ahmed et al. (2024) emphasize that citizen involvement is one of the key factors driving community-driven energy systems. Bokolo (2026) further argues that local energy communities need citizen engagement and inclusive governance if they are to support a fair and sustainable energy transition. In practice, citizen involvement varies across RECs. Some residents participate mainly as members or beneficiaries. Others become prosumers or take part in local decisions, depending on the community’s governance arrangements.

Establishing a REC does not by itself ensure citizen participation. Standal et al. (2023) assess fairness by asking whether relevant stakeholders are recognised, whether they can access information and decision-making processes, and how costs and benefits are allocated. These questions concern recognition as well as distributive and procedural fairness. Bokolo (2026) identifies additional barriers, including uneven project design, limited capacity at the local level, and weak trust in governance. Technical and economic feasibility therefore does not guarantee that residents will participate. They also need understandable information, clear rules for involvement, and entry conditions that they can realistically meet.

2.2 Indicator-Based Assessment for Renewable Energy Communities

As REC research has developed, scholars have increasingly recognized that a small number of technical or economic variables cannot fully describe the overall performance of energy communities. RECs often involve energy efficiency, economic feasibility, social equity, environmental co-benefits, and spatial conditions at the same time. A more systematic indicator-based assessment approach is therefore needed to organize these dimensions. Giannuzzo et al. (2025) argue that REC assessment should avoid restricted and partial analyses, and that Key Performance Indicators (KPIs) should cover multiple domains, including energy, economic, social, and environmental aspects.

In this direction, the Environmental Protocol for Energy Communities proposed by Mutani, Santantonio, and Goulias (2020) provides an important source indicator framework for this research. The study does not limit energy community assessment to energy performance. The protocol covers five areas of REC performance: energy, economic, social, environmental, and territorial. It places the 58 indicators within a common structure that can also be used to compare indicator applicability, thresholds, and data sources. In this thesis, the same structure is retained so that each selected indicator can be traced to the original framework before the full list is reduced for the citizen-facing prototype.

Giannuzzo et al. (2025) classify REC KPIs by thematic domain, intended use, and user group. Their review covers energy, economic, social, and environmental domains. It also records whether an indicator is used for planning, operations, monitoring, or benchmarking. The intended users include policymakers, REC managers, other stakeholders, and community members. This structure makes the practical application and expected audience of each indicator explicit alongside its thematic classification. This classification shows that indicators do not belong statically to a single thematic domain. They also have specific use contexts and target audiences.

Although REC indicator systems are therefore relatively mature, a citizen-facing platform still requires further organization. On the one hand, existing frameworks show that REC assessment must be multidimensional. On the other hand, platform design requires a second screening within these multidimensional indicators, identifying which indicators are more relevant to citizens, which can be calculated under current data conditions, and which are suitable for frontend presentation. The methodology of this thesis is developed on this basis.

2.3 Stakeholder-Oriented Indicator Organization

The actors involved in RECs are not homogeneous, and the meaning of an indicator changes according to the actor who uses it. Some indicators mainly serve local planning and policy judgement. Others are more suitable for project design and investment decisions, while still others are closer to everyday understanding and comparison. In other words, indicators do not exist independently of their users. They are always embedded in specific governance relations, decision tasks, and interpretive contexts.

In their review of REC KPIs, Giannuzzo et al. (2025) already suggest that indicators can be organized by target groups, including policymakers, stakeholders, REC members, and REC managers. This classification is helpful for understanding the use direction of REC indicators, but it remains too broad if directly applied to the platform context of this thesis. Because this thesis focuses on a citizen-facing frontend platform prototype, the existing target-group logic needs to be translated into stakeholder groups that are closer to platform presentation.

The stakeholder categories were not derived from the KPI review alone. They were cross-checked against studies of REC governance, citizen participation, municipal roles, and private-sector involvement. Ahmed et al. (2024) identify citizens and community members alongside policymakers and industry professionals. D'Alpaos and Andreolli (2021) distinguish consumers, prosumers, local authorities, energy utilities, and private actors, and examine the benefits associated with cooperation among them. In the Italian context, Tatti et al. (2023) describe local authorities as promoters and aggregators, while also noting that REC implementation may follow public or private initiatives. Campagna et al. (2024) discuss the different responsibilities of policymakers, citizens, and REC managers in relation to energy-poverty mitigation and benefit sharing.

These distinctions were used to define five groups for the indicator mapping: Citizens, Policy-making entities, Private companies, Health and public services, and Education and research. The mapping records which groups are the primary or secondary users of each indicator.

2.4 Existing REC Geoportals and Energy Platform Precedents

The platform precedents reviewed in this thesis can be divided into three main categories. The first consists of REC geoportals and planning-support platforms, which usually integrate spatial data, energy demand, renewable energy resources, socio-economic variables, and territorial constraints to support planning and scenario comparison. The second consists of techno-economic feasibility tools for RECs or collective self-consumption projects, with a stronger focus on energy balance, incentives, costs, and financial outputs. The third consists of solar and urban energy platforms. These are not necessarily designed specifically for RECs, but they provide useful references for presenting energy information through maps, address search, building selection, charts, and benchmark panels.

The Italian REC geoportal proposed by Mutani et al. (2024) belongs to the first category. It integrates spatial data, load profiles, energy prices, renewable resource availability, technical characteristics, socio-economic conditions, and territorial constraints within a single planning-support framework. Mutani et al. (2026) also emphasize that multi-objective tools for REC design and assessment need to combine geospatial analysis, energy modelling, and socio-economic variables. These studies show how complex datasets can be organized for REC planning and are relevant to this thesis. However, their main users remain planners, local governments, and technical stakeholders, so the interface logic is closer to professional analysis than to the everyday understanding of ordinary citizens.

A second group covers techno-economic assessment tools. In the Villar Pellice study, Mutani et al. (2021) evaluate REC feasibility through self-consumption and self-sufficiency indicators together with cost-optimal analysis. These tools compare alternative project configurations using load profiles, incentive mechanisms, and financial results. They can indicate whether a proposed solution is technically and economically viable, although residents may need additional explanation to interpret the outputs. Costs, returns, and configuration efficiency do not directly show what role residents can take, nor do they allow different participation pathways to be compared from a user perspective.

The third category is closer to the interface focus of this thesis. ITT Torino / Cities on Power, Bologna Solar City, NY Solar Map, Toronto 2030 Platform, and other urban energy maps show how frontend design can improve access to spatial and energy data. Functions such as address search, roof identification, map layers, local statistics, and visual comparison panels provide references for a citizen-facing REC prototype. However, these platforms usually focus on solar potential, urban energy benchmarks, or emissions information. They do not yet fully address REC-specific issues such as energy sharing, participation roles, stakeholder-oriented indicator screening, and preference-based scenario ranking.

Category	Platform	Scope	Users	Main functions	Strengths	Category
REC geoportals and planning-support platforms	GEO4CER	REC/CER territorial planning and dashboard visualization	Planners, municipalities, technical stakeholders	Spatial data integration; renewable resource visualization; territorial comparison; scenario display	Integrates energy, spatial, and landscape information within a unified geographic framework; suitable for regional planning	REC geoportals and planning-support platforms

					and multi-scale decision support	
REC geoportals and planning-support platforms	Italian REC Geoportal (Mutani et al., 2024)	Place-based REC planning and energy-sharing assessment in Italy	Planners, municipalities, stakeholders	GIS integration; place-based analysis; scenario comparison; self-consumption and self-sufficiency assessment	Combines energy demand, renewable resources, socio-economic conditions, and territorial constraints in a planning-support framework	REC geoportals and planning-support platforms
Technical-economic simulators	ENEA RECON	CER / collective self-consumption feasibility assessment	Local authorities, project promoters, stakeholders	Project configuration; load and PV input; energy simulation; economic and financial evaluation	Clearly structures incentive mechanisms, energy-sharing logic, and financial outputs	Technical-economic simulators
Solar and urban energy	ITT Torino / Cities on Power	Building-level rooftop solar	Citizens, building owners, public/privat	Address search; building selection;	Provides an intuitive workflow from	Solar and urban energy

platforms		assessment	e entities	roof polygon drawing; solar potential estimation; economic and environmental outputs	building identification to result visualization	platforms
Solar and urban energy platforms	Bologna Solar City	Rooftop solar radiation and suitability	Citizens, municipal users	Map browsing; address search; roof query; solar suitability display	Presents technical solar data in a concise and accessible form	Solar and urban energy platforms
Solar and urban energy platforms	NY Solar Map	State- and county-level solar information	Citizens, installers, companies, municipalities, non-profits	User-type entry; address search; map layers; statistics dashboard; calculator	Differentiates information access through user entry points, map layers, and regional statistics	Solar and urban energy platforms
Solar and urban energy platforms	Toronto 2030 Platform	District-scale urban energy and emissions governance	Municipalities, building owners, public/private actors	District map; KPI panel; building benchmark; typology	Connects benchmarks and participation-related information	Solar and urban energy platforms

				filter; incentives; participation network	within a broader governance platform	
Solar and urban energy platforms	NYC Energy and Water Performance Map	City-scale building benchmarking	Governance actors, public users, policy users	Filtering; comparison; benchmarking; building performance display	Demonstrates how energy data can support governance through comparison and benchmarking	Solar and urban energy platforms
Solar and urban energy platforms	NYC Block and Lot Energy Map	Block- and lot-scale urban energy mapping	Planners, governance users, researchers	Choropleth map; block-level query; energy intensity comparison	Effectively represents energy information across building and district scales	Solar and urban energy platforms

Table 2.1. Existing REC geoportals and energy platform precedents comparison table

The reviewed platforms provide three useful directions for this thesis. REC geoportals and planning-support platforms offer references for integrating spatial, energy, socio-economic, and territorial data. Techno-economic tools show how feasibility, incentives, energy balance, and financial outputs can be organized. Solar and urban energy platforms are closer to frontend design because they show how maps, address search, charts, and benchmark panels can make technical energy information more readable.

The reviewed platforms cover only parts of the problem addressed in this thesis. RECs geoportals are mainly built for planning and technical assessment. Techno-economic tools evaluate project feasibility. Solar and urban energy platforms are often easier for public users to navigate. Their public-facing design rarely includes RECs participation, energy-sharing arrangements, or indicator selection for citizens. The gap lies in the step before interface design: deciding which RECs indicators should be retained and how they should be presented to citizens. This thesis works on that connection by selecting citizen-relevant indicators and reorganizing them into benefit categories and scenario-based platform modules.

2.5 Citizen-Facing Energy Interfaces and Indicator Translation

Making energy data visible does not ensure that users can interpret it. Research on smart energy systems therefore considers the conditions under which information can support user action. Valkering et al. (2014) relate end-user engagement to users’ motivations, the options available to them, and the barriers they face. Huang et al. (2017), drawing on the YouPower platform, argue that energy information needs to be linked to possible actions. Comparisons and prompts can help users interpret individual indicator values. Recommendations and community interaction can provide further context for deciding how to respond.

Research on user-centred interfaces approaches this issue from a design perspective. Glatz-Reichenbach et al. (2015) argue for an end-user-oriented architecture in which the system structure and graphical interface are developed with users in mind. This principle informs the presentation of indicators in the prototype developed for this thesis. Each value is accompanied by an explanation of what it measures and how it relates to the user’s circumstances. The interface then links these indicators to the comparison of REC participation options.

In this thesis, indicator translation is treated as an intermediate step between technical assessment and interface design. The first task is to rewrite technical indicators as questions that citizens can recognize, such as how much energy the selected area consumes, how much renewable energy is produced locally, and what a given REC scenario may change. The second task is to group the indicators into benefit-oriented outputs, so users are not asked to read a long list of separate values. The outputs are then used in scenario comparison. This allows users to examine differences between participation pathways without relying on a single indicator value. The prototype presents the results under Economic Benefit, Local

Energy Benefit, and Environmental Benefit. Each category remains linked to the original REC indicators and expresses the results through issues that users can recognise, including electricity bills, local renewable energy use, and emissions. The later platform scenario ranking is also based on these three benefit categories.

2.6 Research Gap

The reviewed literature supports this thesis in four ways. REC participation studies explain why citizens can be potential members, prosumers, beneficiaries, and participants in local energy decision-making. Indicator-based assessment studies provide multidimensional ways to evaluate REC performance across energy, economic, social, environmental, and territorial aspects. Stakeholder-oriented research shows that the use of an indicator depends on its intended audience. Local governments, private enterprises, public institutions, and residents may interpret the same value in relation to different decisions. Studies of existing platforms provide reference cases for spatial-data integration and techno-economic assessment. They also show how energy results can be presented to public users.

The reviewed literature leaves one methodological step insufficiently developed for a citizen-facing REC platform. Indicator frameworks specify the variables that may be assessed. Geoportals and simulation tools mainly focus on calculation and display. The remaining issue is the practical screening carried out in this thesis. Indicators need to be checked for citizen relevance and against the available data and scripts. The retained results must then be organised for role identification, benefit interpretation, and scenario comparison.

The analysis begins with the REC indicator framework proposed by Mutani et al. (2020). Each indicator is checked against the available datasets, SQL scripts, and official sources to determine whether it can currently be calculated. The indicators are then mapped to the stakeholder groups most likely to use them. Those relevant to citizens and suitable for frontend presentation form the reduced set used in the prototype. The selected indicators are subsequently reorganized into benefit scores and embedded in the prototype interface, thereby connecting REC technical assessment with platform outputs that residents can more easily understand.

Chapter 3. Methodology

3.1 Overall Research Workflow

The methodology consists of a series of screening and translation steps. The starting point is the 58-indicator framework proposed by Mutani et al. (2020), which is used as the source indicator list for the thesis.Each indicator is checked against the datasets, SQL scripts, official sources, and spatial layers available for the study. A separate review considers whether the resulting value can be explained clearly in the frontend. Indicators supported by the current workflow are calculated directly or estimated with stated assumptions. The remaining indicators are retained as contextual information or left outside the first prototype.

Once calculability has been established, each indicator is assigned to the stakeholder groups most likely to use it. The assignment is based on the indicator’ s meaning and practical use, while its suitability for interface presentation is checked separately. This process separates indicators intended mainly for citizens from those used more often by private companies, policy-making entities, health and public services, or education and research institutions. The citizen-related indicators are screened again to define the smaller set used in the prototype.

Following the citizen-focused screening, each retained indicator is assigned to the benefit category it supports: Economic Benefit, Local Energy Benefit, or Environmental Benefit. These dimensions support scenario comparison and preference-based ranking in the platform. The final step is the development of the citizen-facing prototype, which connects the selected indicators with local energy baseline reading, role identification, benefit explanation, scenario comparison, and preference ranking.

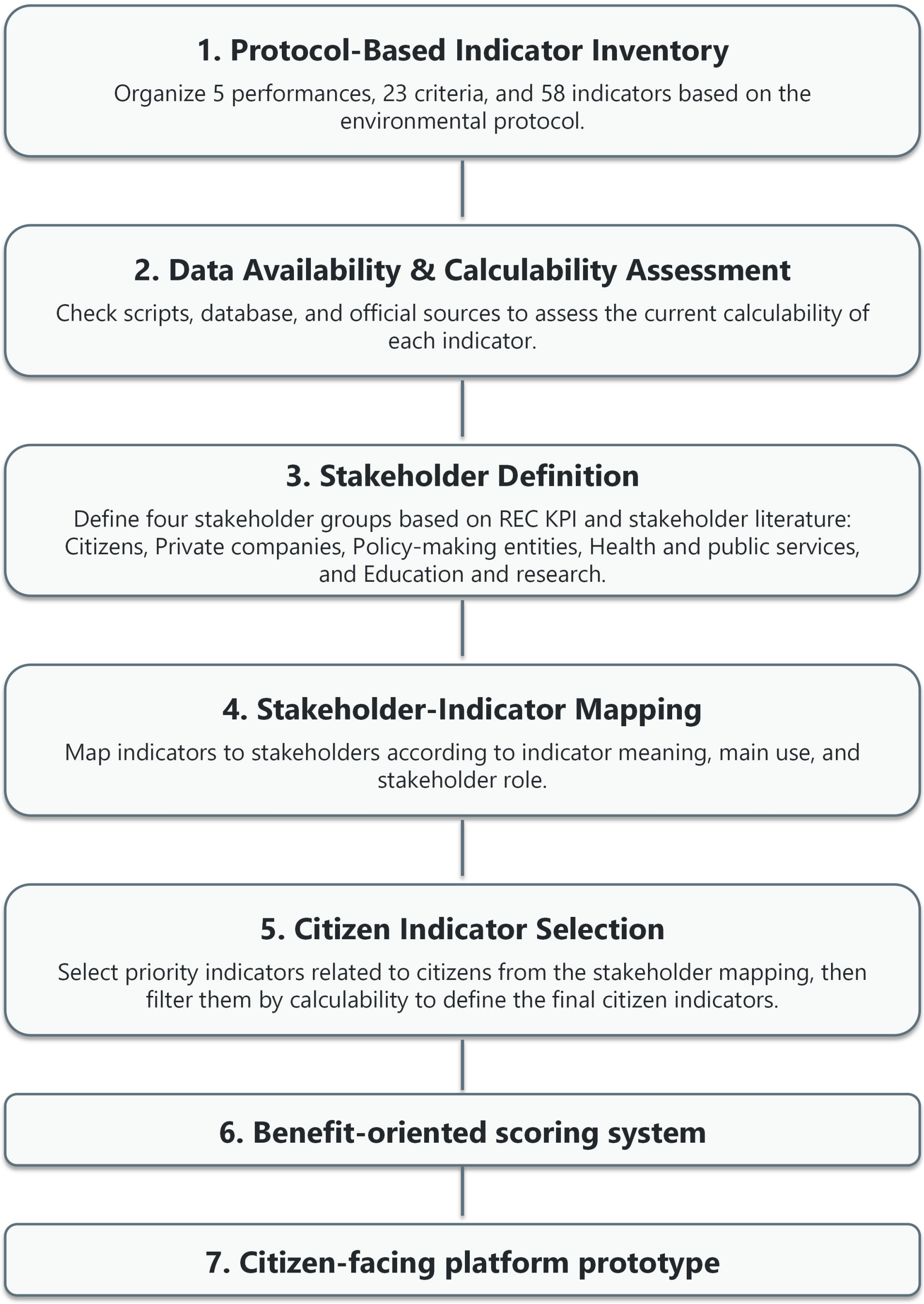

Figure 3.1. Overall research workflow.

3.2 Data Sources and Current Calculability

The source indicator framework for this thesis is the 58 REC indicators proposed by Mutani et al. (2020). These indicators cover five dimensions of REC assessment: energy, economic, social, environmental, and territorial performance. In this research, they are used as the initial indicator pool. Each indicator is then reviewed according to calculability, citizen relevance, and suitability for frontend presentation, and the final prototype indicators are selected from the reduced set.

Before the indicators can be used in the prototype, they need to be checked against the data and processing conditions available in this thesis. The 58 indicators in the source framework depend on different types of information. Some require building-scale data, some depend on regional or national statistics, and others require time profiles, spatial boundaries, or survey data. Their spatial scale, temporal resolution, and statistical definitions are also not always consistent. This research therefore reviews each indicator in terms of data availability and current calculability.

The calculability review assigns each indicator to one of four categories. Category A is used when the available datasets, database fields, SQL scripts, or official sources support direct calculation. Indicators are placed in Category B when a result can be produced only by applying proxy variables, aggregation rules, spatial-boundary assumptions, or a simplified calculation. Category C records indicators that remain relevant but cannot be implemented in the current workflow because required fields or processing steps are missing. Category D is reserved for indicators outside the present calculation scope; these are kept as background information or possible extensions.

For each indicator, the review checks whether the required data are available and whether their spatial scale is compatible with the platform. It then verifies that the indicator can be derived from an existing database field or SQL script. The final check concerns presentation: the resulting value must be clearly explainable in the frontend prototype. For REC/CER-related definitions, the thesis also refers to the official GSE guidelines on Comunita energetiche rinnovabili to ensure that the interpretation of indicators is consistent with the Italian REC implementation framework.

3.3 Stakeholder Group Definition

The stakeholder-indicator mapping in this thesis uses five groups: Citizens, Policy-making entities, Private companies, Health and public services, and Education and research. These groups are adjusted from the literature on REC target users and local energy actors, and are defined according to the practical needs of the platform prototype and indicator screening process.

Citizens form the main reference group for the prototype. In this study, the category covers residents and households, including people with no previous involvement in a REC as well as current members and potential participants. Their position is not uniform. Some use the platform as end users or potential beneficiaries. Others may be affected by REC development or take part in local decisions. Indicators are linked to this group when they help residents interpret local energy conditions or identify a feasible participation role. They are also retained when they support comparison of expected benefits across scenarios.

The Private companies group covers investors, SMEs, project developers, utilities, and energy service companies involved in REC development. Their roles may include feasibility assessment, investment, implementation, or operation. Indicators assigned to this group are used to evaluate techno-economic conditions and installed capacity. They may also inform decisions on operational performance, investment requirements, and whether a project should proceed to implementation.

The Policy-making entities group covers public authorities at municipal, provincial, regional, and national levels. These bodies are responsible for planning and regulation, implementing policy, coordinating across territories, and making decisions in the public interest. In the indicator-mapping table, an indicator is assigned to this group when it supports governance or area-based planning. The group also uses indicators to assess energy-poverty measures and whether REC development is consistent with public policy objectives.

The Health and public services group covers hospitals, welfare facilities, and other buildings or infrastructure used to deliver essential services. It also includes the operators and building managers responsible for these facilities. This group is treated separately from policy-making entities because its indicator needs are tied to service continuity and vulnerable users. Relevant indicators may describe energy vulnerability, the performance of public-service buildings, or exposure to local environmental conditions. Energy vulnerability, public buildings, health facilities, and environmental exposure therefore also need to be interpreted from this group's perspective.

Education and research institutions include schools, universities, and research organizations. Because of their public function, building characteristics, occupancy patterns, and potential role in demonstration, experimentation, and public learning, this research treats them as an independent stakeholder group. Indicators are linked to this group when they describe the energy demand of schools and universities or their integration into REC projects. Indicators used for demonstration and research activities are also included.

The mapping records a primary user group and, where applicable, secondary users for each indicator. An indicator is not treated as exclusive to one stakeholder group. The table shows how its use may change with the decision context. In the next screening stage, these assignments distinguish the indicators retained as core inputs for the citizen-facing prototype from those kept for feasibility assessment, policy support, public-service interpretation, or future development.

Stakeholder group	Definition	Literature basis	Role in indicator selection
Citizens	Residents, households, ordinary citizens, existing REC members, and potential REC participants. In this thesis, they are treated as participants, end-users, beneficiaries or affected actors, and possible co-decision-makers.	Giannuzzo et al. (2025); Ahmed et al. (2024); Standal et al. (2023); D'Alpaos and Andreolli (2021).	Used to identify indicators that can be understood by residents and translated into citizen-facing outputs.
Private companies	Private investors, SMEs, developers, utilities, energy-service actors, and	Giannuzzo et al. (2025); Ahmed et al. (2024); D'Alpaos and	Used to identify technical-economic indicators

	other operational actors involved in REC feasibility, investment, implementation, and operation.	Andreolli (2021); Tatti et al. (2023).	related to feasibility, installed capacity, operation, and business-oriented REC development.
Policy-making entities	Municipal, provincial, regional, national, and other public actors responsible for planning, regulation, policy implementation, territorial coordination, and public-interest decision-making.	Giannuzzo et al. (2025); Tatti et al. (2023); Campagna et al. (2024); D'Alpaos and Andreolli (2021).	Used to identify indicators related to planning, governance, territorial aggregation, policy priorities, and energy-poverty mitigation.
Health and public services	Hospitals, welfare facilities, service infrastructures, public-service operators, and related public-building managers associated with essential service continuity and	Tatti et al. (2023); Campagna et al. (2024); Italian REC and public-building planning literature.	Used to identify indicators related to vulnerability, public-service continuity, and socially sensitive energy or environmental

	vulnerable population support.		conditions.
Education and research	Schools, universities, and research institutions considered as a distinct analytical group because of their public role, building profile, occupancy pattern, and territorial distribution.	Tatti et al. (2023); Italian REC geoportal and CER GIS planning literature.	Used to identify indicators related to institutional demand, public-building integration, and demonstration or experimentation potential.

Table 3.1. Stakeholder group definition table.

3.4 Stakeholder-Indicator Mapping

After the stakeholder groups are defined, the 58 indicators are mapped to the actors with which they are most closely associated. This step clarifies whether an indicator mainly serves citizen communication, business-oriented feasibility analysis, policy-making, public service interpretation, or education and research purposes. It also identifies which indicators can be further translated into citizen-facing prototype content.

Each indicator was reviewed in relation to what it measures and how it is used in practice. The mapping then records the stakeholder groups most likely to rely on the result. Annual renewable energy production is included in the local energy baseline because it describes the amount of renewable energy generated in the selected area. Self-consumption rate and renewable energy self-consumption rate describe how local renewable production is used and shared. They are relevant to citizen-facing communication and to REC operation. Energy dependency reflects the degree to which local demand still relies on external supply, while total greenhouse gas emissions connect the energy system to environmental impact.

Expected use was also considered during the stakeholder mapping. Renewable energy installed capacity is mainly used in technical planning and investment analysis. In the citizen-facing interface, the same indicator is presented as the amount of renewable capacity already installed in the selected area. Territorial aggregation is assigned mainly to policy-making entities because it supports comparison across administrative and energy units. Indicators concerning public buildings or vulnerable services are linked more closely to public institutions. For citizens, priority is given to indicators that clarify local energy use and possible economic or environmental outcomes. Indicators that help identify participation pathways are also retained.

In the mapping table, each indicator is assigned a primary stakeholder, possible secondary stakeholders, and a brief rationale. This makes the reduction of the original 58 indicators more transparent and helps distinguish indicators that can become core platform inputs from those more suitable as background information or future extensions.

3.5 Benefit-Oriented Scoring System

The stakeholder-indicator mapping is used to identify the indicators most relevant to citizens. In this step, citizen relevance is not treated as a broad label. An indicator is selected only when it can help residents understand local energy conditions, potential benefits, or participation pathways. At the same time, the indicator must be calculable with the data and processing tools available in this thesis, or at least be clearly presentable.

The screening produces two groups of indicators. The first group consists of final prototype indicators. These indicators are both citizen-relevant and usable in the current prototype, either through direct calculation or partial estimation. They support baseline cards, benefit scoring, scenario comparison, and preference-based ranking.

Some citizen-relevant indicators cannot yet support the first version of the prototype. This applies to energy poverty, housing comfort, participation capacity, and aspects of local environmental quality. Their calculation would require survey data or external statistics that are not connected to the current workflow. In other cases, the available spatial resolution is too coarse or further processing is still required. These indicators are kept as contextual information and documented for later development. They are not used in the current scoring model.

The scoring system was developed for comparison within the prototype. It places indicators with different units and scoring directions in a common comparison format. The resulting scores are used in the interface to compare participation scenarios. They should not be interpreted as a substitute for a full technical or financial feasibility assessment of an REC project.

Each retained indicator is converted to a score between 0 and 100. Its scoring direction is set according to the meaning of the indicator. Annual renewable energy production, renewable energy installed capacity, and renewable energy self-consumption rate are treated as positive indicators, so the score rises with the observed value. Energy dependency, excess generation, energy price, and total greenhouse gas emissions are treated as negative indicators; lower observed values receive higher scores. Bill-saving and avoided-emission proxies are evaluated against the baseline scenario, using the measured improvement as the scoring input.

Positive indicators:

$$S_i = \min(x_i / B_i * 100, 100)$$

Negative indicators:

$$S_i = \min(B_i / x_i * 100, 100)$$

Improvement indicators:

$$S_i = \min(\Delta x_i / \Delta B_i * 100, 100)$$

In these equations, S_i denotes the normalized score for indicator i, x_i the observed value, and B_i the benchmark, threshold, or scenario reference. For improvement-based indicators, Delta x_i records the change from the baseline scenario, while Delta B_i is the reference improvement used for normalization. Values above 100 are capped. The interface therefore applies one reading rule: higher scores correspond to more favourable outcomes for citizens.

The normalized indicators are then assigned to the benefit categories used in the prototype. Economic Benefit groups indicators related to energy price, estimated energy cost, and bill-saving proxies. Local Energy Benefit combines renewable energy installed capacity, annual renewable energy production, renewable energy self-consumption rate, excess generation, and energy dependency. Together, these indicators describe the availability and local use of renewable energy. Environmental Benefit draws on total greenhouse gas emissions, annual renewable energy production, and energy mix. Avoided-emission proxy indicators are included when the required scenario data are available.

The three category scores are further integrated into the Overall Citizen Benefit Score:

*Overall Citizen Benefit Score = w1 * Economic Benefit Score + w2 * Local Energy Benefit Score + w3 * Environmental Benefit Score*

In the baseline version of the prototype, the three benefit categories use equal weights as a neutral starting point, so that Economic Benefit, Local Energy Benefit, and Environmental Benefit contribute equally to the overall score. In Module 5, the default weights are revised before the scenarios are ranked. Selecting electricity-cost reduction as the main priority gives Economic Benefit a larger contribution to the score. A preference for locally produced and shared renewable energy shifts the weighting towards Local Energy Benefit. When emission reduction is selected, Environmental Benefit carries more weight in the final ranking.

Within the prototype, the scores provide an explanatory comparison of REC participation options. Each score can still be traced to the indicators selected from the original REC framework. The interface presents these results under Economic Benefit, Local Energy Benefit, and Environmental Benefit so that users can compare the outcomes of different scenarios. The scores are limited to this interface function. A complete REC assessment would still require technical simulation, financial feasibility analysis, and verification against the applicable regulatory framework.

Several indicators relevant to citizens remain outside the current scoring structure. Indicators on energy poverty, housing comfort, citizen participation, PM10 and PM2.5, and recycling are retained as contextual information for possible use in later versions. They remain useful for interpreting social, residential, and local environmental conditions, but additional data or finer spatial processing is needed before they can become stable scoring inputs.

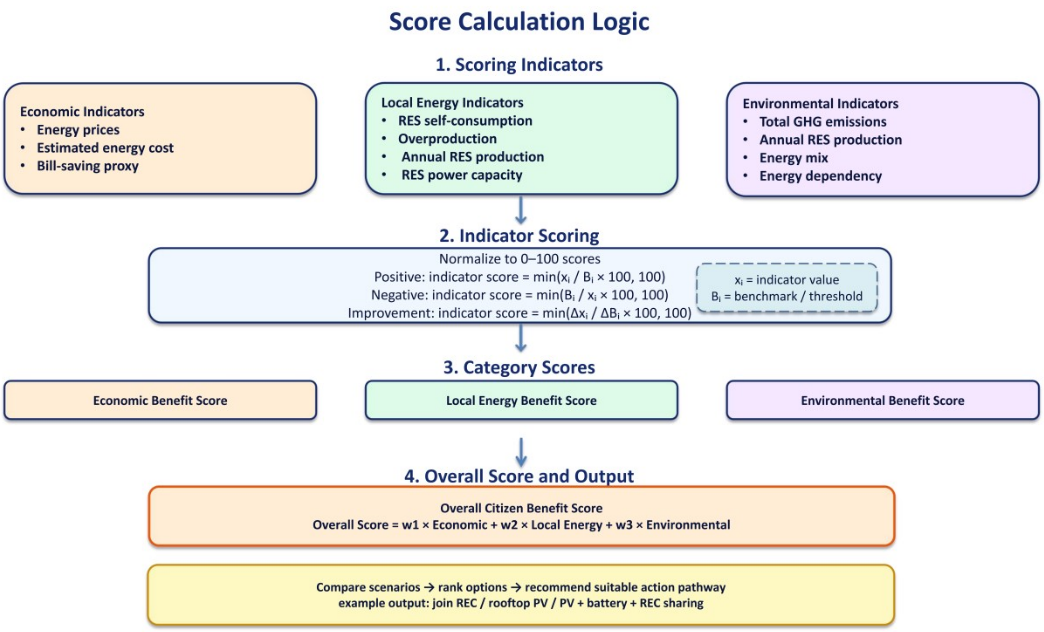

Figure 3.2. Benefit-oriented scoring system figure

3.6 Citizen-Facing Platform Prototype Development

The prototype tests how selected REC indicators can be translated from backend assessment logic into a frontend structure that residents can read and interact with. It builds on indicator screening, calculability assessment, stakeholder mapping, and benefit scoring, but its focus is interface translation: how indicators can become baseline cards, role questions, benefit categories, scenario comparisons, and preference-based ranking outputs.

The prototype uses a dashboard-based frontend structure. Its data logic is supported by the final prototype indicators selected in the previous sections, while its interface logic is organized around five modules: Local Energy Story, My Role in the REC, Benefit Explorer, Scenario Explorer, and Preferences and Community Signals.

The modules are arranged as a sequence of user tasks. Local Energy Story first presents the regional energy baseline. My Role in the REC then uses housing characteristics and participation conditions to narrow the roles available to the user. In Benefit Explorer, the retained indicators are presented under Economic Benefit, Local Energy Benefit, and Environmental Benefit. Scenario Explorer applies this structure when comparing the available participation pathways. The final module, Preferences and Community Signals, revises the ranking using the priorities entered by the user and returns an initial recommendation.

Module 1: Local Energy Story

Module 1 opens with the energy baseline for the selected area. In the Lombardia case used in the prototype, total energy consumption is read alongside annual renewable energy production to show whether local production falls short of or exceeds demand. Installed renewable capacity, energy dependency, and total greenhouse gas emissions provide additional context. The results are shown through a map, summary cards, and an energy-mix chart, with short notes explaining the values and the local conditions that may affect REC development.

This module also helps users form an initial understanding of the spatial context behind the energy data. Building morphology, local renewable energy potential, urban-rural conditions, and other site factors are used as background for the following modules. Energy indicators therefore need to be interpreted together with the local conditions that may affect REC participation.

Module 2: My Role in the REC

My Role in the RECs connects the regional baseline with the user's own situation. Module 2 begins by recording the user’s housing situation and building type. It then asks about roof access, authority to make building-related decisions, and the user’s preferred form of participation. These answers are used to match the user with one of four roles: Community Consumer, Rooftop Prosumer Candidate, Shared Building Participant, or Potential RECs Member.

The same answers are used as preliminary feasibility constraints in the role-matching step. Direct roof access keeps rooftop PV and PV plus REC sharing among the available pathways. For apartment residents, individual rooftop options may depend on approval from other residents or the property manager. The module therefore also considers shared-building PV or participation in a REC as a consumer. The resulting role reflects the user’s stated interest together with the options allowed by the building and decision-making context.

Module 3: Benefit Explorer

In Benefit Explorer, the retained indicators are reported under Economic Benefit, Local Energy Benefit, and Environmental Benefit. Economic Benefit uses energy price, estimated energy cost, and bill-saving proxies. Local Energy Benefit draws on renewable energy self-consumption rate, excess generation, annual renewable energy production, and installed renewable capacity. Together, these values describe the availability and local use of renewable energy. Environmental Benefit is based on total greenhouse gas emissions, annual renewable energy production, energy mix, and avoided-emission proxy indicators when scenario data are available.

These benefits are presented through score cards, gauges, indicator contribution charts, and explanatory cards. Scores must be interpreted together with the local conditions and user-specific conditions identified in previous modules. The same score may therefore imply different practical opportunities for a rooftop owner, an apartment resident, or a user who can only join a REC as a consumer.

Module 4: Scenario Explorer

Module 4 compares five participation pathways included in the prototype. These are joining a REC only, rooftop PV, apartment PV, PV plus REC sharing, and PV plus battery plus REC. A common scoring rule is applied to every pathway. The interface places the Economic Benefit, Local Energy Benefit, Environmental Benefit, and Overall Benefit results side by side.

Benefit scores in Module 4 are read together with a preliminary feasibility check. Rooftop PV remains an available pathway when the user has access to the roof, although implementation would still require a separate assessment of technical suitability. Shared-building or apartment PV also depends on collective approval and cannot be selected through an individual decision alone. For users who do not control a roof, joining the REC as a consumer remains a more accessible option. The interface therefore keeps feasibility conditions alongside the benefit results instead of treating the highest score as an automatic recommendation.

Module 5: Preferences and Community Signals

Module 5 records the user’s priority before the final scenario ranking is calculated. Users may prioritise electricity-cost reduction, local renewable energy use, or emission reduction. A balanced setting is available when no single benefit is given priority. The selected option changes the weights assigned to Economic Benefit, Local Energy Benefit, and Environmental Benefit in the Overall Citizen Benefit Score.

When the user selects electricity-cost reduction, Economic Benefit contributes more to the final score. A preference for producing and using renewable energy locally gives greater influence to Local Energy Benefit in the ranking. If emission reduction is prioritized, Environmental Benefit receives a higher weight. The final recommendation is also checked again against the conditions identified in previous modules, so the recommended pathway is constrained by both user values and feasibility. When a pathway depends on collective willingness, shared-building participation, or broader local support, community-oriented factors appear as additional explanatory signals.

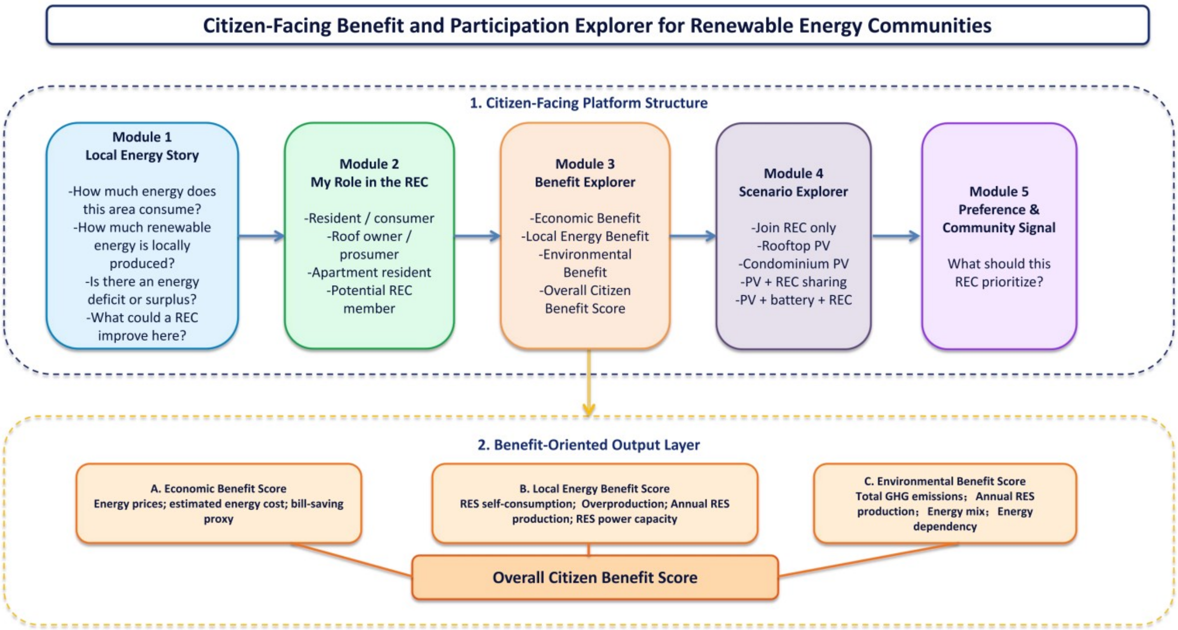

Figure 3.2. Citizen-facing platform structure figure

3.7 Spatial Constraints and Planning Context

Scenario interpretation in the REC platform prototype combines benefit scores with site-specific feasibility information. Even when a scenario has a high economic, local energy, or environmental score, implementation may still be difficult if building conditions, grid boundaries, or the planning context do not support it. The methodology therefore introduces spatial constraints and planning context between indicator calculation and scenario ranking as a feasibility check.

The current prototype considers three types of constraints. The first is the urban-rural spatial context, which describes territorial conditions through settlement density, building morphology, renewable energy potential, and the space available for collective energy action.

The second is the primary substation service boundary. In Italy, REC participation and energy sharing are linked to the relevant cabina primaria area, so buildings and energy facilities need to be interpreted not only by geographic location but also within the electricity network service boundary. The third type includes urban planning and regulatory conditions, such as planning rules, heritage protection, permitting procedures, and other local approval constraints that may affect implementation.

These constraints are used across the five prototype modules. Module 1 reads the local energy baseline together with the selected area's spatial environment, including resource conditions and preliminary limitations. Module 2 uses building type, roof access, and decision-making rights to identify realistic participation pathways. Module 3 interprets benefit scores with local and user-specific conditions, since the same score may have different practical meanings for different users. Modules 4 and 5 combine expected benefits with feasibility checks during scenario comparison and final ranking. The final pathway depends on both the score and the conditions under which that pathway could be implemented.

Chapter 4. Platform Data Preparation Workflow

4.1 Source Datasets and Territorial Harmonization

The platform data preparation workflow uses several territorial and energy datasets with different spatial scales and attribute structures. In this thesis, the preparation stage links building records with energy-consumption data, renewable-energy production records, spatial constraint layers, and selected socio-economic attributes. The resulting database provides the spatial relationships and attribute fields required for indicator calculation and interface outputs. This approach follows Mutani, Vocale, and Javanroodi (2023), who identify geographic database construction and calibration as part of place-based energy modelling. Their study points to the need to reconcile spatial reference systems, attribute definitions, and units of analysis.

For the workflow, the datasets are organised into four functional groups. Spatial reference layers provide administrative boundaries, building footprints, and the territorial units used for spatial joins and aggregation. Energy-related sources supply electricity-demand estimates, installed capacity, and records of existing renewable generation. Resource layers are read together with spatial and regulatory constraints when assessing local renewable energy conditions and possible implementation limits. Household, population, vulnerability, and other local data provide the socio-economic context. This organisation follows GIS-based CER planning studies in Italy, where consumption data are combined with renewable resources, territorial constraints, and social variables for spatial analysis and platform outputs (Mutani et al., 2024).

The workflow also draws on the author's experience in ENEA-related research activities. This work included the organization of Italian national building databases, building energy modelling, and the linkage of spatial datasets used for energy analysis. More specifically, it involved building geometry harmonization, use classification, energy consumption estimation, renewable energy information, and spatial linkage procedures. In this thesis, this experience helps define how raw data are cleaned, linked, and converted into inputs for indicator calculation and prototype visualization.

Territorial harmonization includes several processing steps: unifying coordinate reference systems and spatial units, standardizing attribute fields, checking missing or inconsistent records and correcting them where possible, and then converting raw data into platform-ready indicator tables, map layers, and scenario parameters through spatial joins, aggregation, and reclassification. City-scale modelling studies in Milan use a similar logic, combining open databases, EPC-related information, and QGIS-derived variables to support building energy modelling, consumption analysis, solar production estimation, and scenario assessment (Mutani et al., 2023). The baseline indicators and prototype outputs in this thesis are therefore based on harmonized data rather than on raw sources with different formats and scales.

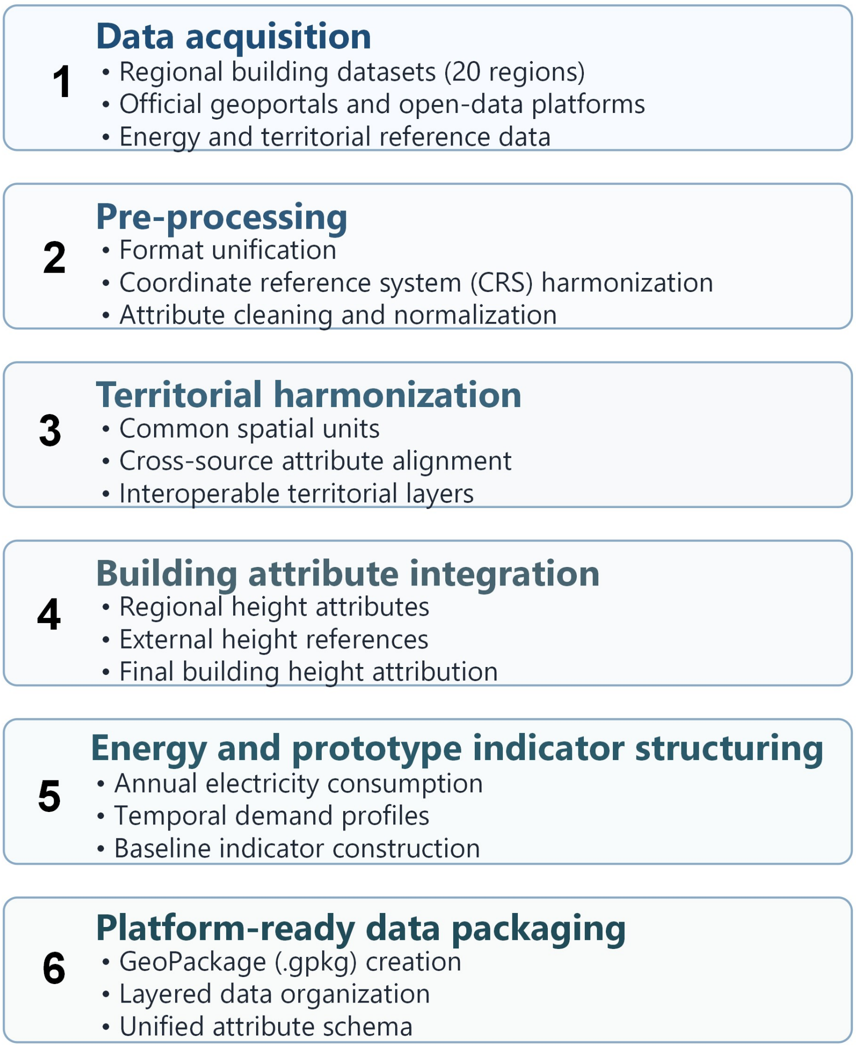

Figure 4.1. Workflow of source data preparation and territorial harmonization for the platform prototype.

Typology	Input Data	Sub-category	Source	License
Building databases: type of use and classification				
Built-up environment / Type of users / Building classification	Regional technical maps and geo-topographic databases (CTR/DBGT) — one per region	Vector building footprint layers with use classification attributes	See Appendix A for the full list of regional sources and download links	Various — predominantly CC-BY 4.0 (Italian Regions)
	OpenStreetMap	Regional and municipal building data are used as a supplementary source for height and use information	https://download.geofabrik.de/europe/italy.html	Open Data Commons Open Database License (ODbL)
Socio-economic characteristics	ISTAT — Basi Territoriali e Variabili Censuarie	Census section boundaries and building stock variables (E8–E20): number of floors, construction period, building type	https://www.istat.it/notizia/basi-territoriali-e-variabili-censuarie/	Open Data
	ISTAT — Censimento della Popolazione e delle Abitazioni (2011, 2021)	Number of resident households and population per census section	https://www.istat.it/notizia/basi-territoriali-e-variabili-censuarie/	Open Data
DTM and DSM				

Digital Terrain Model	TINItaly — DTM (10 m) — national baseline	Terrain elevation raster used as the base DTM across all regions	https://tinitaly.pi.ingv.it/Download_Area1_1.html	CC BY (INGV)
Digital Surface Model	Regional DSMs — where available	Resolution varies by region: 0.5 m (Friuli-Venezia Giulia), 1 m (Toscana, Sardegna partial), 2 m (Valle d'Aosta), 5 m (Piemonte, Lombardia, Basilicata, Campania, Calabria), 8 m (Puglia archival)	See Appendix A for regional DSM download links	Various — Open Data / CC-BY (Italian Regions)
	European Urban Atlas — Building Height 2012	Pan-European raster of building heights at 10 m resolution; used as a reference for major urban areas	https://land.copernicus.eu/en/products/urban-atlas/building-height-2012	Copernicus Land Monitoring Service
Energy consumption profiles				

Energy consumption data	ARERA — Residential electricity consumption profiles	Monthly average hourly consumption per residential customer per province; separate profiles for working days (FR) and non-working days (FS)	https://reporting.arera.it/SASVisualAnalytics/?reportUri=%2Freports%2Freports%2Fff58199d-f010-4cfd-a5d1-32c1d6359c05&sso_guest=true&reportViewOnly=true&reportContextBar=false&sas-welcome=false	Open Data (ARERA)
	ENEA — Rapporto Annuale sull'Efficienza Energetica 2025 — Schede Regionali	Regional annual energy efficiency reports providing reference benchmarks for consumption by sector and region	https://www.efficienzaenergetica.enea.it/vi-segnaliamo/rapporto-annuale-sull-efficienza-energetica-2025-schede-regionali.html	Open Data (ENEA)
Administrative boundaries	ISTAT — Provincial boundaries (prov_2024)	Vector layer of Italian province boundaries used for spatial aggregation of consumption results	https://www.istat.it/notizia/basi-territoriali-e-variabili-censuarie/	Open Data

Infrastructure	National primary electrical cabin service areas (primarycabins_2025)	Polygon layer of primary substation service areas used for sub-provincial spatial disaggregation		
Actual energy production by RES				
Energy production data	GSE — Atlaimpianti portal	Geo-referenced database of registered renewable energy plants; attributes include location, installed capacity (kW), and source type (solar, wind, hydroelectricity, biomass, geothermal)	https://www.gse.it/dati-e-scenari/atlaimpianti	Database pursuant to art. 1 L. 22/4/1941 n. 633
	Province-level utilization hours per RES type	Equivalent full-load hours per year by energy source and province		

Table 4.1. Main source datasets used for platform data preparation

4.2 Building Classification and Geometric Completion

Before energy modelling, records from the regional building datasets were brought into a common structure. The source layers used different fields and local labels for building use, while some records lacked reliable geometry or height attributes. Preparation involved harmonising the use codes, completing missing geometric attributes, and assigning each building to the spatial units used for aggregation.

Building-use classification began with the local descriptions stored in each regional layer. These labels were mapped to the standard sectors used in the calculation tables: residential, primary, secondary, tertiary, and non-building. Mixed residential buildings were kept as a separate category because their expected load pattern differs from that of purely residential records. More detailed codes were introduced where the energy profile required them, including schools, healthcare facilities, transport hubs, commercial and public services, and intermittent-use facilities. The original labels remained in a reference field for checking. Standardised codes were used for load-profile assignment and aggregation across the regional datasets.

Geometric completion focused on building height and the variables derived from it. Height values from the regional database were kept when the source attribute was considered reliable. Missing or doubtful records were checked against external height datasets and supporting statistics. Where no usable height value was available, the estimate relied on floor-related information and the floor-height assumptions adopted in the workflow. The final height was then used to estimate floor count where necessary, while building volume was calculated from height and footprint area.

Once the use codes and height attributes had been completed, each retained building record contained the fields required by the energy model: footprint area, final height, estimated floor count, volume, and a standardised use code. Minor ancillary structures, invalid geometries, and records labelled as non-buildings were moved outside the main calculation set because they could not support reliable energy estimates. The cleaned layer was then used for annual consumption calculations and load-profile assignment. It also provided the building-level reference for socio-economic linkage and indicator aggregation.

Once the building records had been standardised, each record was spatially linked to the boundaries required for the later calculations and maps. The building remained the base object for its geometric and use-related attributes. Census and statistical zones supplied household, population, building-age, and vulnerability data. Municipal, provincial, and regional boundaries were used for territorial summaries and comparison. Consumption and renewable-production results were also aggregated by primary-substation service area, the electricity-network boundary used in REC-related analysis.

New Code	**Sector (R/P/S/T)**	**Energy Consumption Type**	**Examples**	**Energy Characteristics**
RL (Residential - Low Demand)	R (Residential)	Only residential	Apartments, houses, dormitories	Pure residential: morning and evening peaks, low daytime demand
RM (residential mixed)	R (Residential)	Mixed-use residential	Student dorms, Gated communities, mixed-use residential with offices, shops on lower floors	High demand. Similar to RL, but with higher daytime consumption due to mixed residential and commercial use. HVAC
PA (Primary - Agriculture & Extraction)	P (Primary)	Agriculture, Mining, Fishing	Farms, greenhouses, fisheries, mines	Seasonal peaks, heating, irrigation, refrigeration
SP (Secondary -Production & Industry)	S (Secondary)	Manufacturing & Heavy Industry	Factories, refineries, warehouses	Heavy machinery, continuous or shift-based operation
TC (Tertiary - Commercial & Public Services)	T (Tertiary)	Shops, offices, government, museums, places of culture, military, hotel, religious, medical outpatient	Shops, banks, offices, administrative buildings, supermarkets, gyms, cinemas, church, military, police station, prison, dental clinic, family practice	Daytime peak (offices, shops). High HVAC and lighting demand; stable operation of IT and service systems. Some facilities (e.g., churches, police stations) operate also during weekends.
TT (Tertiary - Transport)	T (Tertiary)	Transport hubs	Train stations, airports	Large transport hubs operate daily or 24/7. Main energy uses: lighting, HVAC. The load pattern follows passenger traffic.
TI (Tertiary – Intermittent Use)	T (Tertiary)	Entertainment, stadium	Theatres, auditoriums, stadiums, sports fields, tennis court	Very high peak loads during events, but low or near-zero Otherwise, usage concentrated on specific hours/days (e.g., concerts, sports).
TS (Tertiary - School)	T (Tertiary)	Schools	Primary and secondary schools, universities, training centers	Daytime use, HVAC, lighting, no weekend use, seasonal
TH (Tertiary -	T (Tertiary)	Hospitals	General hospital,	Continuous 24/7 use.

New Code	Sector (R/P/S/T)	Energy Consumption Type	Examples	Energy Characteristics
Healthcare)			specialized hospital, children's hospital	High demand from lighting, air conditioning, medical devices, and support systems, high hot water demand
Others	-	Infrastructure or undefined features (non-building)	Telecom towers, open equipment areas, and track platforms, technical shafts, or elements with NULL attributes	There is no energy use, or it isn't a building

Table 4.X Building classification

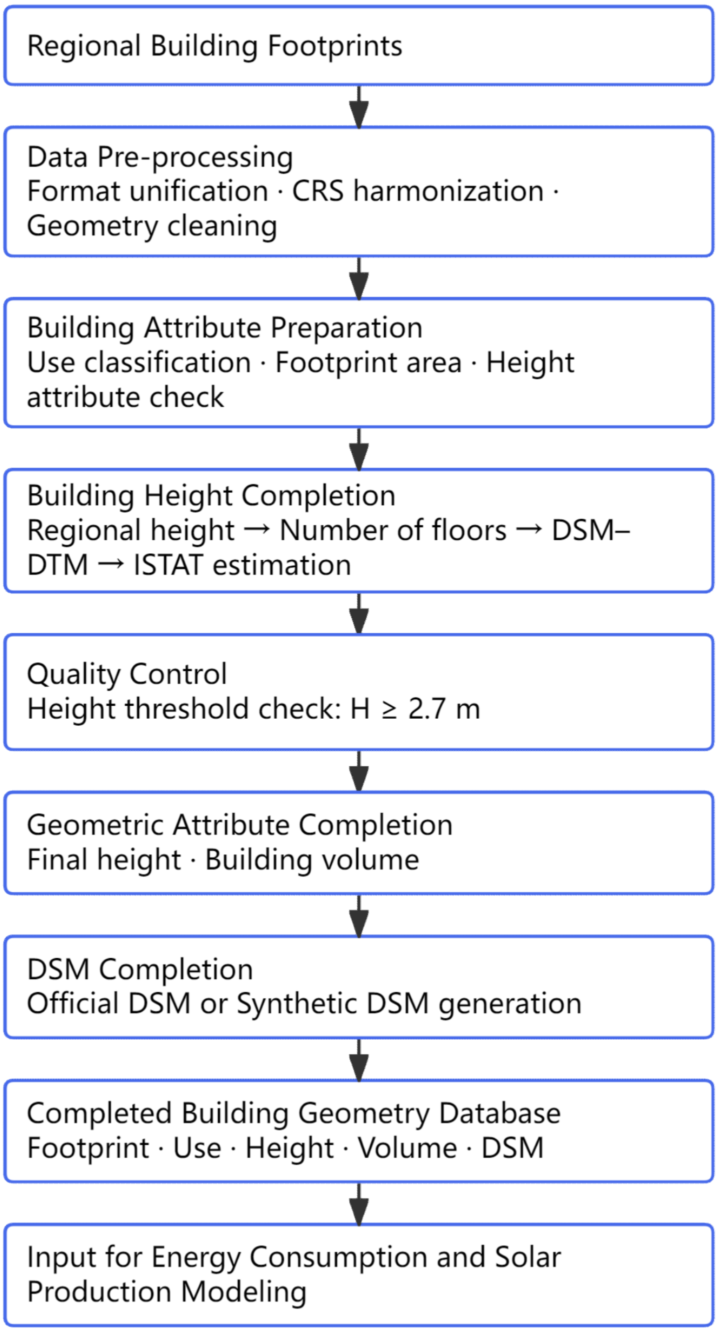

Figure 4.X. Geometric completion workflow

Aggregation unit	Main role	Typical linked data	Use in platform
Building unit	Basic geometric and semantic object	Footprint, height, use type, volume	Base unit for later calculation and aggregation
Census / statistical	Carrier of socio-	Population,	Support contextual

unit	economic attributes	households, building age, vulnerability	and downscaled social-energy variables
Administrative unit	Territorial comparison and map representation	Municipality, province, region	Support area-based visualization and comparison
Energy-related unit	Functional energy aggregation	Primary cabin, REC-related boundary, production-consumption grouping	Support energy matching and REC-oriented analysis

Table 4.2. Main spatial linkage units and their analytical roles

4.3 Energy Consumption and Actual Production Modeling

To construct the baseline energy variables used in the platform prototype, this research models energy consumption and existing renewable energy production. The workflow is implemented in PostgreSQL and produces two types of outputs: annual totals and hourly profiles. The spatial units defined in the previous section ensure that consumption and production results are comparable at provincial and primary substation service-area scales.

Consumption modelling begins by linking each building to its province and primary substation service area. Most records are assigned through a direct spatial match. Buildings located on or close to a boundary are assigned to the nearest service area when the direct match fails.

Census-zone data are then used to allocate the number of households to individual buildings. The allocation is based on each building's share of residential volume within the corresponding census zone:

Households in building = (building residential volume / total residential volume in census zone) x total households in census zone

Building-scale annual electricity consumption is calculated from the estimated number of households and ARERA provincial average annual household electricity consumption:

Annual electricity consumption = households in building x average annual household electricity consumption (kWh)

The annual value is then distributed into an hourly profile using ARERA month-hour-day-type coefficients. For each building, month, and FR/FS day type, hourly electricity consumption is calculated as follows:

Hourly electricity consumption[hour] = annual electricity consumption x monthly share x hourly profile coefficient[hour, month, FR/FS]

This produces a building-scale hourly electricity consumption array, which can be aggregated by province, primary substation service area, or other spatial units used by the platform.

On the production side, the same spatial matching logic is used to assign registered renewable energy facilities to provinces and primary substation service areas. Annual production is calculated from installed capacity and provincial annual full-load hours:

Annual production_kWh = installed capacity_kW x annual full-load hours

The full-load hours are taken from provincial lookup tables differentiated by energy type. The original facility categories are also standardized as solar PV, wind, hydropower, biomass, and geothermal, allowing production results from different energy sources to be compared.

Annual production is then converted into hourly production arrays using profile coefficients by energy type and province:

Hourly production[hour] = annual production_kWh x hourly profile coefficient[hour, month, FR/FS, energy type, province]

The final baseline dataset combines building-scale consumption and facility-scale production. The main outputs include annual energy consumption, hourly consumption arrays, annual renewable energy production, hourly production arrays, and aggregated results at provincial and primary substation service-area levels. These outputs support the calculation of total energy consumption, annual renewable energy production, local coverage rate, energy gap, and other prototype indicators used in later platform modules.

After the data processing described above, the raw database is converted into three types of outputs that directly support the platform prototype. The first type consists of territorial baseline indicators, including total energy consumption, annual renewable energy production, renewable energy installed capacity, local coverage rate, and energy gap. The second type consists of consumption and production profiles organized by month, day type, and hour. The third type consists of aggregation tables and intermediate variables needed for later scoring, comparison, and frontend presentation. Through this conversion, backend calculation results are reorganized into a unified data structure that supports the platform's baseline cards, comparison panels, and prototype indicators.

Chapter 5. Indicator Assessment and Citizen-Oriented Indicator Selection

5.1 Overview of the 58-Indicator Inventory

This chapter explains how the initial 58 REC indicators are reviewed and reduced to the indicators actually used in the platform prototype. The starting point is the framework proposed by Mutani et al. (2020), which includes five performance dimensions, 23 criteria, and 58 indicators covering the energy, economic, social, environmental, and territorial aspects of REC assessment. The 58-indicator framework provides the reference inventory for the assessment. Each indicator is checked against the available data and scripts before being examined in the stakeholder mapping and citizen-oriented selection.

The framework was retained because it was developed for energy-community assessment and links every indicator to a defined performance dimension and criterion. These links are preserved when the list is reduced, allowing each prototype indicator to be traced back to the original REC assessment structure.

The study works from the existing 58-indicator framework; developing a separate REC indicator system is outside its scope. Each indicator is checked against the available datasets and SQL scripts to establish whether it can be used under the current processing conditions. Its relevance to citizens and suitability for frontend presentation are reviewed separately.

The complete list remains the reference pool from which the prototype indicators are selected. Some are suitable for technical analysis, policy support, or contextual explanation. Others, because they are calculable, readable, and directly related to the platform modules, are more suitable for the citizen-facing prototype. The following sections explain the composition of the original list, the results of the calculability assessment, and the final set of indicators included in the prototype.

5.2 Calculability Assessment Results

The calculability review assigned each of the 58 indicators to one of four categories based on its usability in the current workflow. Indicators supported directly by the existing databases, SQL scripts, or official sources were placed in Category A. Category B was used when a value could be estimated only after introducing proxies, aggregation rules, scenario assumptions, or spatial-boundary definitions. Category C retained indicators relevant to REC assessment that could not yet be produced because the required data or processing steps were missing; this included survey-based variables and indicators requiring finer spatial resolution. Category D contained indicators outside the present implementation scope, so they were not used in the current calculations.

The review confirmed that the complete 58-indicator inventory could not be implemented in the first platform version. A subset was already supported by the available datasets, SQL scripts, spatial layers, or official reference sources. Other indicators lacked the data or processing steps required for a stable calculation, while some could not yet be explained clearly in the citizen-facing interface. These findings were used to define the core inputs for the baseline cards, benefit scores, and scenario comparison. Indicators without sufficient support remain outside the current calculations. Where they still provide useful context, they are documented for later development.

Performance	Prototype-relevant indicators (A/B)	Contextual or later-stage indicators (C/D)
Energy Performance	Total consumption; Consumption by sector; Annual total production; Energy mix; RES power capacity; Annual RES production; Plurality of end users; Plurality of energy subject; Self-consumption; RES self-consumption; Overproduction; Energy dependency	Energy intensity; Energy efficiency (Savings rate); Share of RES in transport system; Storage system; System resiliency
Economic Performance	Energy prices; Occupation rate; Average income (of families)	Absolute poverty; Poverty risk; Arrears on utility bills; Inability to keep home warm; Access to electricity; Local economic growth; Graduates rate; Access to internet; Inequality income distribution
Social Performance	Housing deprivation; Access to public transport; Citizen participation	Life expectation / Oldness index; Unmet medical needs; Education degree; Comfortably warm home; Comfortably cool home; Maintenance state of buildings; Intermodality of transport system; Sense of community
Environmental Performance	Hydroelectric withdrawal; Protection of water sources; Water quality; Total GHG emissions; GHG emissions by sector	Annual level of PM10-PM2.5; Land use; Forest protection; Biodiversity protection; Special hazardous waste; Recycling rate; Landfill waste rate
Territorial Performance	Territorial / municipal aggregation; Contiguity of electric network	Connectivity of the road network; Efficiency of public transport; Availability of safe cycling routes; Strategic territorial plans

Table 5.1. Calculability results of the 58 indicators in relation to prototype implementation.

5.3 Stakeholder-Indicator Mapping Results

The stakeholder-indicator mapping shows that indicator relevance depends on the use context and on the actors who need to interpret the indicator. Indicators within the same performance dimension do not necessarily serve the same stakeholders. The mapping is therefore carried out at the level of individual indicators, rather than assigning an entire performance dimension to one stakeholder group.

For citizens, the most relevant indicators are those that can be translated into everyday questions concerning local energy use, potential benefits, environmental impact, and participation pathways. Total energy consumption, annual renewable energy production, self-consumption rate, renewable energy self-consumption rate, energy dependency, energy price, and total greenhouse gas emissions are core examples. These indicators help residents understand how much energy is used locally, how much renewable energy is produced, how much local production can be used within the community, how dependent the area remains on external supply, and what economic or environmental effects REC participation may bring.

The mapping linked private companies mainly to indicators used in techno-economic feasibility, investment, and implementation decisions. Renewable energy installed capacity and annual production inform project sizing and expected output. Storage variables, energy price, and self-consumption indicators are more closely related to operating strategy and energy management. Several of these results can also be shown in the citizen-facing interface. Their primary role in the mapping, however, is to support project feasibility and implementation.

The mapping linked policy-making entities mainly to indicators used in territorial planning and public coordination. Consumption by sector and energy intensity support comparison of demand patterns across areas and economic activities. Territorial or municipal aggregation and electric-network contiguity inform decisions on how REC areas may be spatially organised. Energy dependency and energy-poverty indicators draw attention to places where reliance on external supply or social vulnerability may require public action. Other social and territorial indicators are retained when they provide evidence for spatial coordination or targeted support.

The mapping linked Health and public services to indicators used to identify vulnerable populations and facilities with specific service needs. Life expectancy or the ageing index and unmet healthcare needs provide demographic and healthcare context. Inability to keep the dwelling warm, winter and summer housing comfort, PM10 and PM2.5 levels, and public-building demand describe conditions that may affect the planning of REC measures for these areas or facilities. Most of these indicators remain outside the first prototype’s scoring system because they depend on household surveys, health-service records, or environmental data at a finer spatial scale.

The mapping associates Education and research institutions with the energy demand of schools, universities, and research facilities. These institutions may also host demonstration projects or contribute technical knowledge to REC development. Education level and institutional building demand provide background information on this stakeholder group. Public-building integration, local renewable energy production, and territorial aggregation are more directly related to the planning of demonstration or research activities. In the current prototype, these indicators remain contextual or later-stage inputs and do not enter the main citizen-facing score.

The mapping showed that citizen-oriented screening had to be carried out indicator by indicator; no performance dimension could be retained or removed as a whole. A single performance dimension may contain indicators relevant to residents, enterprises, public decision-makers, health and public services, and education and research institutions at the same time. The subsequent screening therefore focuses on individual indicators, identifying which are most relevant to citizens, which can be calculated or presented with existing data, and which can be translated into baseline indicators, benefit scores, or scenario comparison inputs in the platform prototype.

5.4 Citizen Priority Indicators

Citizen priority indicators are selected from the indicators that pass the previous calculability assessment and stakeholder mapping. An indicator is retained only if it can answer questions that residents may ask in the REC context, such as how much energy is used locally, how much renewable energy is produced, how dependent the area is on external supply, what economic effects may occur, and what environmental impacts are involved. The indicator must also be calculable, or at least clearly presentable using the data available in the prototype.

The review produces a larger set of citizen-relevant indicators, but only some can be used in the first version of the prototype. Some indicators are suitable as core inputs for scoring and scenario comparison, while others are better suited to explaining the local baseline or providing background information. When data related to social vulnerability, participation, housing comfort, or local environmental quality are insufficient to support stable scoring, these indicators are retained as potential extensions.

The final prototype indicators include total energy consumption, renewable energy installed capacity, annual renewable energy production, energy mix, self-consumption rate, renewable energy self-consumption rate, excess generation, energy dependency, energy price, and total greenhouse gas emissions. These indicators are selected because they can connect to the existing data workflow and be translated into information that residents can read in the interface.

In the platform, total energy consumption defines the demand baseline. Renewable energy installed capacity records the existing generation base, and annual renewable energy production reports its output. The energy mix identifies the sources contributing to that production. Self-consumption rate and renewable energy self-consumption rate show how much generation is used within the local area. Excess generation records output that is not matched by local demand, while energy dependency indicates continued reliance on external supply. Energy price informs the economic reading of the scenarios. Total greenhouse gas emissions provide the environmental reference. These indicators are then reorganized into three platform outputs: Economic Benefit, Local Energy Benefit, and Environmental Benefit.

Final Prototype Indicators

No.	Indicator	Performance	Threshold value	Threshold type	Assessment method	Current calculability	Why / short reason	Citizen-facing meaning	Possible representation
1	Total consumption	Energy Performance	> 0.5 GWh/year	Regulatory threshold	Assess whether the annual electricity consumption of the EC is greater than 0.5 GWh.	A	The current scripts can construct building-scale annual and hourly electricity consumption.	How much electricity the area or community needs each year; this is the demand baseline for understanding renewable coverage and potential bill savings.	Demand baseline card; annual consumption chart; map by building or area.
2	RES power capacity	Energy Performance	> 6.5 kW per capita	National target threshold	Assess whether renewable installed capacity per capita reaches the threshold.	A	The plants layer directly contains installed power (potenza).	How much renewable energy capacity already exists, or could potentially exist, in the local area; comparable to PV potential in citizen solar portals.	Capacity card; map layer; building or REC-area potential summary.
3	Annual RES production	Energy Performance	> 35% of total production	Regulatory threshold	Calculate RES electricity production divided by total electricity production; values above 35% are considered compliant.	A	Yearly production can be directly aggregated by RES type.	How much local green electricity the community produces each year; one of the most direct renewable-benefit indicators.	Annual RES production card; bar chart; scenario comparison.
4	Energy mix	Energy Performance	> 2 RES systems	Regulatory threshold	Assess whether more than two renewable energy systems are present, such as PV, hydro, or biomass.	A	SQL2 maps ai_fonte to solar, wind, hydro, biomass, and geothermal sources.	Which renewable energy sources are present locally; this helps citizens form a readable community energy profile.	Donut chart; energy-source badges; map filter by RES type.
5	Self-consumption	Energy Performance	> 70% of total production	Regulatory threshold	Calculate locally self-consumed electricity divided by total electricity production; values above 70% are considered compliant.	B	It can be estimated through hourly matching, but the REC aggregation or sharing boundary must be defined.	How much electricity produced by the community is actually used locally; a core citizen-facing REC benefit.	Percentage card; daily or hourly matching curve; baseline vs REC scenario.
6	RES self-consumption	Energy Performance	> 70% of total RES production	Regulatory threshold	Calculate locally self-consumed RES electricity divided by total RES production; values above 70% are considered compliant.	B	It can be estimated, but hourly RES production must be matched with local electricity load.	How much locally generated green electricity is actually used locally; this highlights the renewable benefit more directly than general self-consumption.	Renewable self-consumption card; RES matching chart; scenario comparison.
7	Overproduction	Energy Performance	< 30% of total production	Regulatory threshold	Calculate surplus electricity exported or unused locally divided by total production; values below 30% are considered compliant.	B	Hourly arrays are available for estimating time-series surplus, but scenario and aggregation rules are still required.	Whether too much local green electricity is not used locally; this can be translated as surplus electricity.	Surplus electricity card; hourly surplus curve; suggested action note.
8	Energy dependency	Energy Performance	< 30% of total demand	Regulatory threshold	Calculate the demand not covered by local production divided by total demand; values below 30% are considered compliant.	B	It can be derived from the production-consumption balance, but a matching logic is required.	How much electricity demand still depends on the external grid; suitable for expressing community energy independence.	Dependency score; covered vs uncovered demand chart; scenario comparison.
9	Energy prices	Economic Performance	< 0.16-0.20 EUR/kWh	Reference threshold	Assess whether the electricity price is below the reference value; it can also be used as an economic input.	B	The current SQL database does not include a tariff table, but ARERA and ENEA RECON can provide price inputs.	The economic input most directly perceived by residents; it is also the basis for calculating bill savings or cost reduction.	Tariff assumption card; editable price input; bill-saving scenario input.
10	Total GHG emissions	Environmental Performance	< 41.6 kton/year	National target threshold	Calculate annual total greenhouse gas emissions; values below 41.6 kton/year are considered compliant.	B	Electricity-related CO2 can be estimated from consumption, production, and emission factors, but this is not measured total GHG across all sectors.	The emission-reduction effect of the community or area; an environmental co-benefit that citizens can easily understand.	CO2 emissions or avoided CO2 card; baseline vs REC comparison; environmental benefit label.

Table 5.2. Full final prototype indicator table for the citizen-facing REC platform.

5.5 Contextual Indicators for Future Extension

During citizen-oriented screening, several indicators remain relevant for public interpretation but are not included in the first scoring system. These include arrears on utility bills, inability to keep the dwelling warm, winter housing comfort, summer housing comfort, citizen participation, PM10-PM2.5, and recycling rate. These measures add context on households’ ability to afford energy and maintain adequate thermal comfort. Citizen participation reflects the local capacity for collective involvement, while PM10 and PM2.5 levels and the recycling rate describe air quality and municipal waste-management conditions.

The main reason is data availability. Arrears on utility bills, thermal comfort, and subjective housing conditions usually depend on survey or household-scale information. Citizen participation requires local governance or participation data that are difficult to standardize across areas. PM10-PM2.5 and recycling rate can often be obtained from environmental or municipal datasets, but their spatial resolution does not always match the building, primary substation service area, or scenario units used in the prototype. If these indicators were placed directly in the same scoring formula, the stability of the results would decrease and the explanation to users would become more difficult.

These indicators remain outside the current score and are used only to provide contextual information. They indicate when a scenario may need to be interpreted differently across locations. High energy-affordability pressure or poor housing comfort may point to a need for additional household support. Limited participation capacity may instead require more local engagement before a collective pathway is proposed, while air-quality and waste-management indicators provide a separate environmental context. A later platform version could display these measures through context cards or vulnerability filters once comparable local data are available. Their use as weighting factors would require a separate validation of the data and weighting rules.

Chapter 6. Prototype Results and Discussion

6.1 Prototype Implementation

The platform prototype developed in this thesis is positioned as a citizen-facing frontend interface for RECs. It reorganizes the indicator screening, benefit scoring, and scenario comparison logic developed in the previous chapters into an information interface that ordinary residents can read, compare, and use for an initial judgement.

Existing REC geoportals, energy dashboards, and techno-economic tools usually give greater weight to spatial data integration, energy system modelling, policy support, or investment feasibility assessment. Their main users are often planners, local governments, project developers, or technical actors. The prototype therefore starts from the perspective of a resident seeking to understand how a REC relates to the selected area, their building conditions, and the participation options available to them..

The five modules are arranged around a sequence of user tasks. Users begin by reviewing regional energy demand, renewable generation, and emissions in Local Energy Story. My Role in the REC then relates this context to the user’s housing and participation conditions. Benefit Explorer presents Economic Benefit, Local Energy Benefit, and Environmental Benefit, while Scenario Explorer compares the available REC pathways using the same scoring structure. Finally, the Preferences and Community Signals module reorders scenario results according to the user's level of concern for different benefit dimensions. This process moves gradually from regional context to personal role, benefit interpretation, and scenario judgement, avoiding the direct presentation of a complete and complex technical indicator system to residents.

Prototype implementation relies mainly on three types of input data. The first type is local energy context data, which describe current regional energy demand, supply, and renewable energy conditions, including total energy consumption, annual renewable energy production, renewable energy installed capacity, energy dependency, and total greenhouse gas emissions. The second input group records the user’s role and building conditions, including building type, roof access, participation mode, and stated priorities. These fields are used in My Role in the REC to narrow the available participation pathways. The third group stores the Economic Benefit, Local Energy Benefit, Environmental Benefit, and Overall Benefit values for each scenario, together with the preference weights used by Benefit Explorer, Scenario Explorer, and Preferences and Community Signals.

Implementation began by converting the indicator and scenario results into data tables that could be called by the interface. Separate tables stored the regional baseline, role-matching conditions, benefit scores, and scenario comparisons. The Lombardia extent and basemap established the geographic frame. The page sequence was arranged to move from the regional context to the user profile, followed by benefit interpretation and scenario ranking. These components were combined in a web prototype where users can select a role, switch between scenarios, change preference weights, and view the resulting ranking.

The implementation provides a visual test of how the citizen-facing REC logic works in the interface. It shows how the indicator selection, benefit-oriented scoring, and scenario comparison developed in the previous chapters become baseline cards, role-matching results, benefit explanations, scenario comparison panels, and preference-ranking outputs. The related toolchain includes data table preparation, spatial data processing, interface design, and frontend prototype development, as summarized in Table 6.2.

Tool	Role in the prototype	Output
Excel / Google Sheets	Organizes indicators, scenario values, weights, and benefit scores	Structured input tables used by the prototype logic
QGIS	Prepares the Lombardy map and spatial background	Basemap and geographic layers used for interface presentation
Figma	Designs interface layouts, module structures, and user flows	Visual prototype mock-ups and page designs
Vibe coding / React	Builds the interactive web prototype	Clickable and interactive frontend prototype

Table 6.3. Tools used for prototype implementation

6.2 Prototype Overview

The platform prototype contains five sequential modules: Local Energy Story, My Role in the REC, Benefit Explorer, Scenario Explorer, and Preferences and Community Signals. This order follows the way an ordinary user may move from local energy context, to their own possible participation position, to comparison among participation pathways. The structure turns scattered technical indicators, scenario results, and benefit dimensions into a gradual citizen-facing reading process.

More specifically, Local Energy Story establishes an overall understanding of the selected area's energy baseline. My Role in the REC connects the regional energy issue to the user's own housing conditions and participation possibilities. Benefit Explorer presents the benefit priorities relevant to the current user profile. Scenario Explorer organizes comparisons among different REC participation pathways. Finally, Preferences and Community Signals introduces user preferences into the ranking process and generates a recommended pathway and community tendency cues.

6.3 Local Energy Context Representation

Local Energy Story is the starting module of the platform prototype. Before users enter role selection, benefit comparison, and scenario ranking, the module introduces the energy condition of the selected area. The module reads energy consumption against renewable production. Installed capacity, external dependency, and emissions add the context needed to explain the remaining gap and its relevance to REC development.

At the top of the page, a navigation bar links the five modules. A short statement below it interprets the selected area’s energy condition. In the Lombardia demonstration, it notes that consumption exceeds local renewable production, external dependency remains high, and available renewable potential is not fully used. This statement gives users a reference point before they examine the indicator cards.

The main content is divided into four interface blocks. Where is this area? locates the selected territory on the map and shows the positions of renewable-energy facilities. What is happening now? presents the baseline through five cards: Total Energy Consumption, Annual RES Production, RES Power Capacity, Energy Dependency, and Total GHG Emissions. Short status labels help users identify the main conditions without relying on raw values alone.

What is the problem? compares demand with local renewable generation. The Production vs Consumption chart is read together with the local coverage rate and energy gap, making the imbalance visible. Why does it matter? relates this gap to REC development by explaining how external dependency, unused renewable resources, and local emissions affect opportunities for local energy use and shared benefits.

The indicators are read in a defined order. Total Energy Consumption sets the demand baseline. Annual RES Production records current local output, while RES Power Capacity shows the installed generation base. Energy Dependency measures continued reliance on external supply, and Total GHG Emissions provides the environmental reference. Read together, the values describe demand, local production, the remaining shortfall, and its local implications.

Local Energy Story supplies the common baseline for the modules that follow. My Role in the REC carries this local context into questions about the user’s housing situation and available participation options. It also provides the basis for later benefit and scenario modules, where scores are explained, pathways are compared, and the reasons why different REC options may produce different outcomes are clarified.

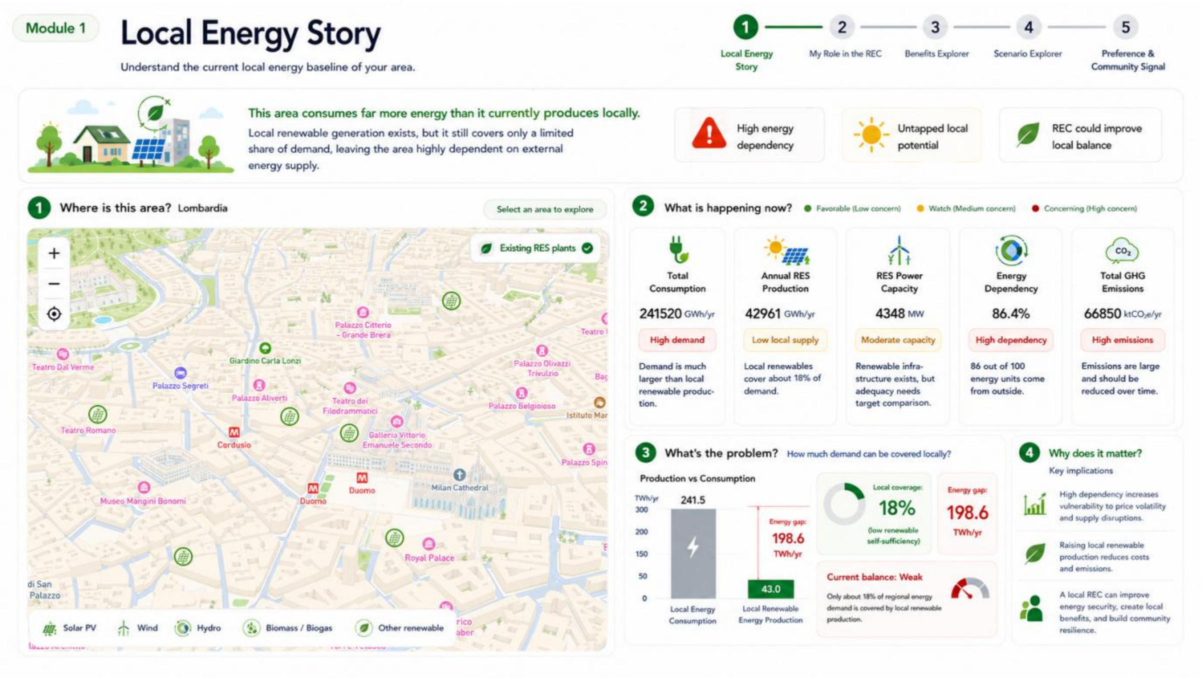

Figure 6.3. Local Energy Story interface

6.4 Citizen Role Identification

My Role in the REC is the second module of the platform prototype, placed after the local energy baseline and before benefit explanation and scenario comparison. This module translates the regional energy condition presented in Module 1 into participation questions related to the user's own situation. It shows users which REC roles are compatible with their situation and which benefits or scenarios warrant further attention. The output is a role match and a preliminary participation pathway. The user's benefit preference is also passed to the later modules.

The interface keeps the initial choices limited. Area 1 offers four entry points based on common concerns: household energy use, rooftop solar, collective participation, and general interest in a REC. Users can therefore begin with a familiar issue, such as an electricity bill, roof access, apartment cooperation, or local energy sharing. This first choice sets a provisional role, which is revised after the detailed questions.

The detailed questions test the conditions that affect participation. Who can make energy-related decisions? checks whether the user can decide on the roof or other energy assets. This answer receives a high role-matching weight because control over these resources determines which pathways are available. What can you contribute to the REC? records electricity demand, roof space, existing PV, willingness to join a collective project, or community support. How much do you want to participate? distinguishes between joining as a consumer, taking part in a shared-building project, investing in renewable generation, and seeking information only. Which benefit matters most to you? records the user's priority for the later benefit and ranking modules.

Role matching uses a rule-based score matrix. Each answer contributes to Community Consumer, Rooftop Prosumer Candidate, Shared-Building Participant, or Potential REC Member. A score of +3 marks a strong match, +2 a moderate match, +1 a supporting signal, and 0 no identified relationship.

Score	Interpretation
+3	Strong matching condition that directly indicates a likely role
+2	Moderate matching condition that suggests a role but requires confirmation
+1	Weak supporting signal used mainly for ranking
0	No clear relationship with the role

Table 6.x. Role-matching score interpretation

Answer / Signal	Community Consumer	Rooftop Prosumer Candidate	Shared-Building Participant	Potential REC Member
Can decide directly	0	+3	0	0
Shared decision with residents	+1	0	+3	0
Cannot decide but can join	+3	0	+1	+1
Rooftop space / existing PV	0	+3	+1	0
Electricity demand	+3	0	0	+1
Learn more for now	0	0	0	+3
Community fairness priority	+1	0	+1	+2

Role scores are calculated as follows:

$$\textit{Role score} = \textit{Area 1 score} + \textit{Q1 score} + \textit{Q2 score} + \textit{Q3 score} + \textit{Q4 score}$$

Q1, Q2, and Q3 carry more weight because they describe the user’s decision rights, available contribution, and intended level of participation. Q4 mainly sets the benefit weights used later, although it can add a small supporting value to the role score.

Tied scores are resolved by checking practical conditions before preferences. Decision rights are considered first, followed by the type of contribution and the user’s willingness to participate. Benefit preference and the initial entry choice are used only after these checks. This order gives priority to roof access, control over the building, available resources, and the ability to join a collective scheme.

The current prototype returns one of four preliminary roles. Community Consumer applies to users who mainly contribute electricity demand and expect shared REC benefits. Rooftop Prosumer Candidate applies when roof space, existing PV, or a realistic opportunity to install generation is available. Shared-Building Participant covers apartment, multi-household, and neighborhood arrangements that require collective decisions. Potential REC Member is used when the technical conditions remain unclear but the user is interested in learning about, supporting, or later joining a REC.

Each result includes a short explanation and a suggested route into the following modules. It also identifies the benefit dimension to examine first. Community Consumers are directed toward REC membership and shared-benefit scenarios. Rooftop Prosumer Candidates are shown rooftop PV and PV-plus-REC options. Shared-Building Participants are linked to apartment or collective-building pathways. Potential REC Members receive introductory information and options requiring a lower initial commitment.

Module 2 combines the initial entry choice with the user’s decision rights, available resources, intended participation level, and benefit priority. The interaction remains brief, but the result reflects the conditions entered by the user. The matched role becomes the basis for later modules, where benefits are explained, scenarios are compared, and final recommendations are adjusted according to the user profile.

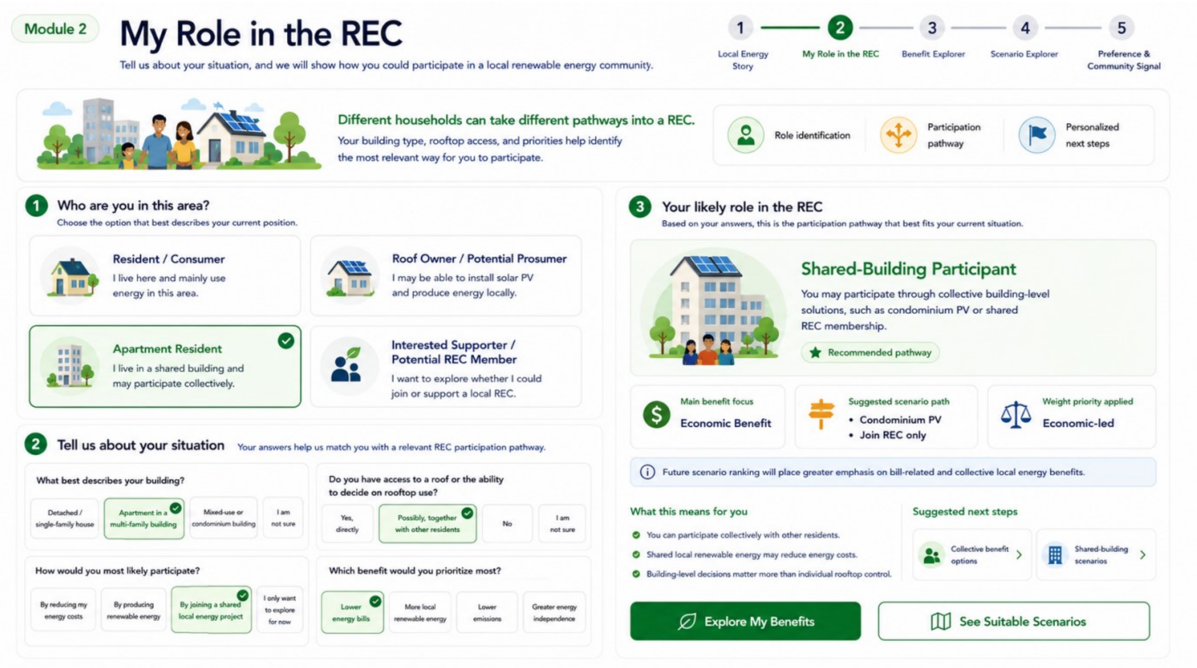

Figure 6.4. My Role in the REC interface

6.5 Benefit Exploration and Indicator Translation

Benefit Explorer is the third interface module in the platform prototype and follows the local energy baseline and user role matching. At this stage, the platform further judges which benefits are most relevant to the current user. The selected technical indicators are presented under Economic Benefit, Local Energy Benefit, and Environmental Benefit. Spatial and planning constraints are shown alongside the scores to indicate whether the corresponding opportunities are compatible with the current building and territorial conditions.

The page opens with a benefit-profile summary based on the matched role and the priority selected by the user. It identifies the benefit category that deserves closer attention for this profile. A Rooftop Prosumer Candidate may receive stronger Local Energy or Environmental signals. A Community Consumer may be directed first to Economic Benefit and information on shared benefits.

Three benefit cards form the main content of the module. Each card shows its title, relevance score, a short explanation, keyword tags, and the indicators used in the calculation. Economic Benefit uses energy price, estimated energy cost, and bill-saving proxies. Local Energy Benefit reports local renewable use, self-consumption, shared energy, and external dependency. Environmental Benefit draws on emissions, energy mix, and the contribution of renewable generation to environmental improvement.

A separate constraints layer checks whether the reported benefits can lead to a feasible participation pathway. Building location, roof conditions, and planning or heritage rules are considered first. The interface also checks the primary-substation boundary, the possible REC perimeter, and grid-connection conditions. Resource availability, existing capacity, and suitability for additional PV provide a further technical check. These constraints do not change the benefit score itself. They determine whether a later scenario is retained, downgraded, or flagged for further assessment.

In Module 3, the scores are explanatory outputs. They show what each benefit category means, which indicators contribute to it, and why it is relevant to the matched role and stated preference. The constraints layer adds the spatial and planning conditions needed to interpret those scores. The same benefit potential may point to different participation pathways under different building conditions, spatial boundaries, and planning constraints. This prepares the Scenario Explorer, where comparison is based on benefit scores, preliminary feasibility, and spatial fit.

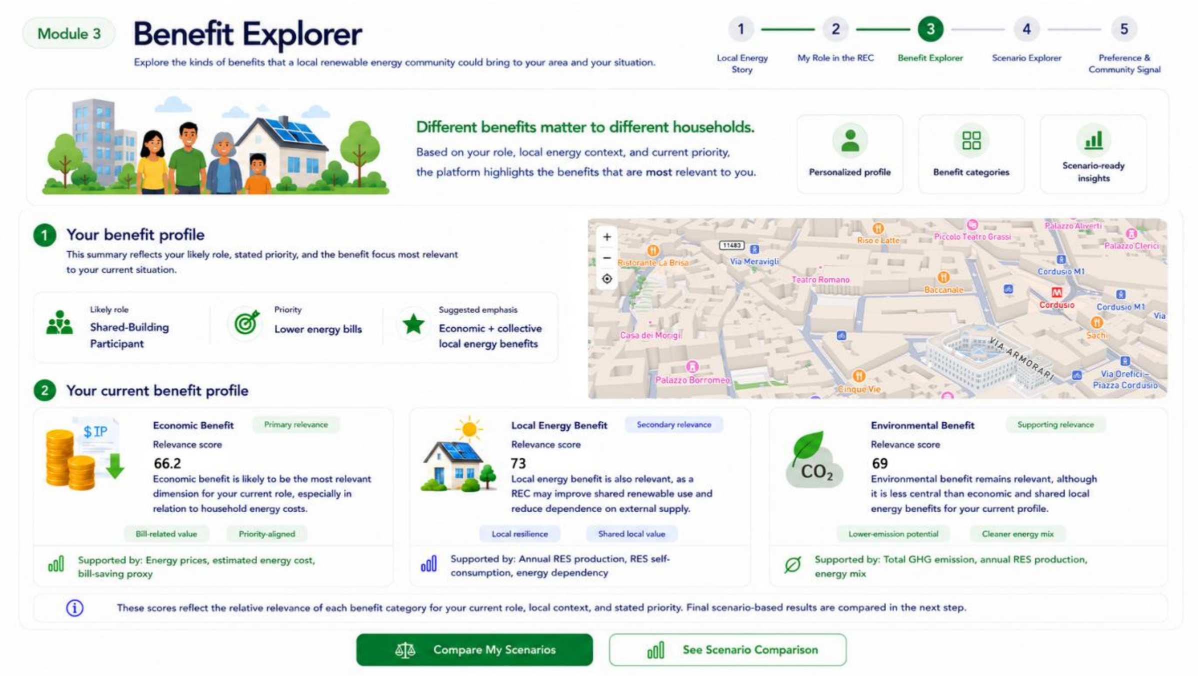

Figure 6.5. Benefit Explorer interface

6.6 Scenario Comparison and Preference-Based Ranking

After the local energy baseline, role matching, and benefit analysis are completed, the platform moves to scenario comparison and final interpretation. At this point, the platform reads the user profile together with the local energy context and stated benefit priority to identify pathways that are valuable and provisionally feasible.

Scenario Explorer compares five pathways: joining a REC as a consumer, rooftop PV, apartment PV, PV with REC sharing, and PV with battery storage and REC participation. The same scoring rules are applied to every pathway, so Economic Benefit, Local Energy Benefit, Environmental Benefit, and Overall Benefit can be compared on a common basis. The comparison does not rely only on scores. It is also explained in relation to building conditions, roof accessibility, participation requirements, and the local context, so that superficially attractive scenarios can be distinguished from scenarios that are actually feasible for a specific user.

Preferences and Community Signals adds a second layer of interpretation. Users can state whether they care more about lowering electricity bills, increasing local renewable energy use, reducing emissions, or achieving a more balanced outcome. The selected priorities change the weights of the three benefit categories before the final ranking is calculated. The result is then checked against the feasibility conditions recorded in the earlier modules, preventing a high score from becoming an automatic recommendation.

The interface presents the result as a ranked set of pathways, with one preferred option and one or more alternatives. The preferred pathway is the option that best matches the user’s conditions, local context, and weighted benefit priorities. Alternative options remain visible in the interface for comparison, especially when other pathways perform better under different combinations of benefits and constraints. For pathways that depend on collective participation, shared-building coordination, or broader local support, community-oriented factors are displayed as additional explanatory signals.

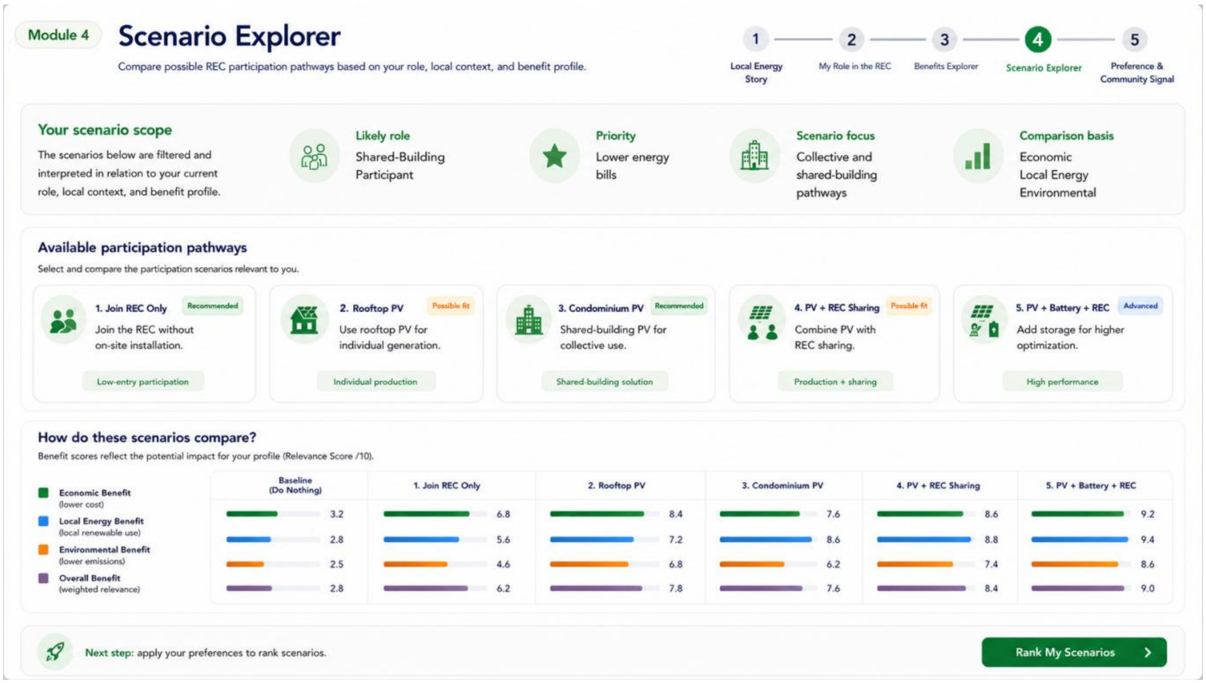

Figure 6.6. Scenario Explorer interface

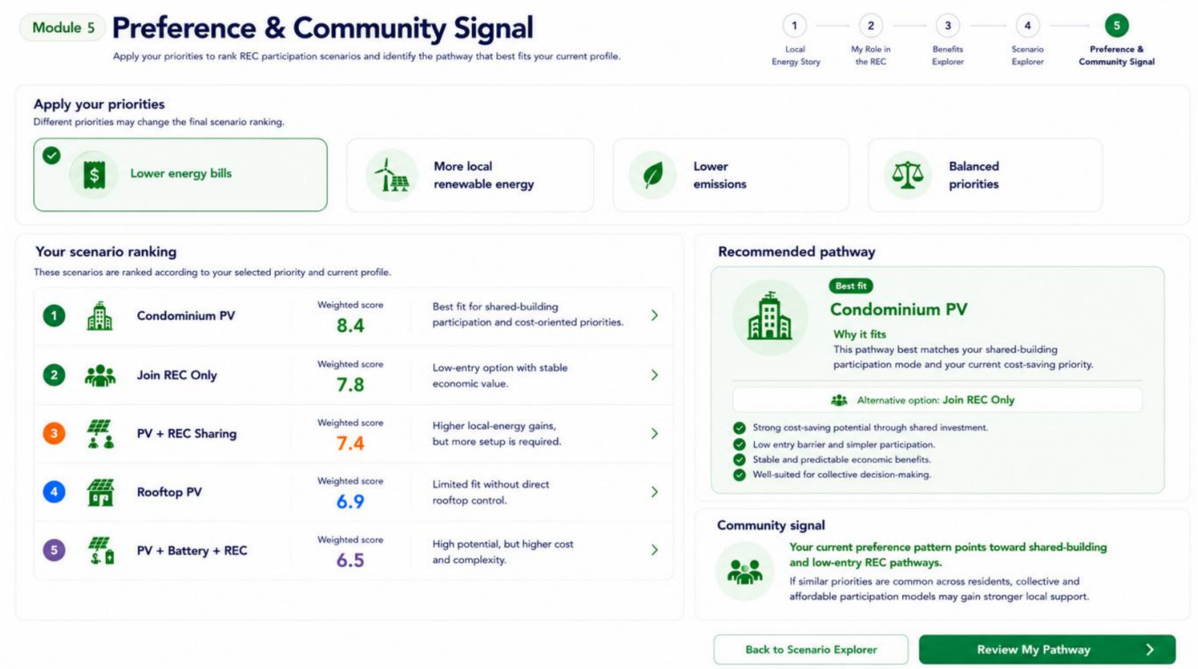

Figure 6.7. Preferences and Community Signals interface

6.7 Discussion of Prototype Usefulness and Limitations

The platform prototype in this research is mainly used to translate REC technical indicators into citizen-facing interface information. For ordinary users, indicators such as self-consumption, self-sufficiency, energy dependency, or GHG emissions are not intuitive in themselves. The prototype places these indicators within a workflow of local energy story, role identification, benefit interpretation, and scenario comparison, allowing users to understand the possible effects of different REC participation modes from the perspective of a specific place and their own conditions.

The value of this prototype first lies in the way information is organized. Geoportals and spatial information platforms can transform scattered data into browsable and comparable territorial information, thereby supporting public understanding and local decision-making (Gamez 2019). In this research, maps, building locations, energy baselines, and benefit cards together form a frontend explanatory layer. Technical data are no longer only backend calculation results, but can be used by residents to understand the energy condition of their area.

Second, the prototype connects scenario comparison with self-consumption and self-sufficiency. Existing research shows that, in urban energy communities, PV, storage, and user composition significantly affect self-consumption and self-sufficiency rates (Todeschi et al. 2021). This research therefore does not display a single benefit score only. Instead, it compares economic, local energy, and environmental benefits across different participation pathways, so that users can see the relative differences among options.

Another value of the platform is the inclusion of a constraints layer. REC feasibility is affected by building conditions, renewable energy resources, infrastructure boundaries, and planning restrictions. Chicco et al. (2024) also note that REC planning needs to combine renewable resource availability, technical suitability, and territorial constraints. On this basis, Module 3 introduces spatial and planning constraints to explain whether certain benefits have preliminary implementation conditions.

The prototype remains an early-stage implementation. Its scenario results use simplified assumptions and serve only to explain differences between participation pathways. They do not replace a complete energy simulation, financial feasibility study, or engineering design. A more detailed version would require hourly matching of demand and generation, current electricity prices, investment and incentive data, a defined storage-control strategy, and more complete electricity-network boundaries.

Public understanding also depends on trust, local capacity, and the fairness of participation. Bokolo (2026) links engagement in local energy communities to governance arrangements, trust, and the ability of residents to participate. User testing is therefore needed to determine whether residents interpret the benefit scores, scenario labels, and recommendation rules as intended.

The prototype sets out one practical route for converting REC indicators into citizen-facing outputs. It brings technical indicators, spatial constraints, and user preferences into one frontend workflow and offers an initial example of a public-facing layer for REC geoportals. Future work should improve spatial constraint data, add more complete economic and social indicators, and test the interface with users.

Chapter 7. Conclusion

This thesis examined how REC technical indicators can be translated into citizen-facing interface information. Using the 58 indicators of Mutani et al. (2020) as the source inventory, the study checked which indicators could be supported by the available datasets and SQL scripts, mapped their relevance to different stakeholder groups, and selected those suitable for citizen-facing use. The retained set was organised as Economic Benefit, Local Energy Benefit, and Environmental Benefit, then implemented across Local Energy Story, My Role in the REC, Benefit Explorer, Scenario Explorer, and Preferences and Community Signals.

The findings indicate that technical suitability alone is not enough for an indicator to enter a public interface. Its value for citizens depends on whether it clarifies a concrete question: how dependent the area remains on external supply, how much demand local renewable generation can cover, what participation may change, and how the available REC pathways differ. The thesis therefore defines a sequence that moves from calculability checking and stakeholder mapping to indicator selection, benefit scoring, and frontend representation. The prototype applies this sequence in a working interface.

The thesis contributes a linked workflow that carries the indicator framework through screening, stakeholder interpretation, scoring, and interface implementation. This workflow is demonstrated through a citizen-facing REC prototype; a fully deployed geoportal remains outside the scope of the study. The current calculation does not yet include several survey-based social indicators, fine-scale environmental measures, or complete planning constraints.

Further development should first strengthen these data inputs and the rules used to filter infeasible scenarios. User testing is then needed to determine whether residents understand the scores, scenario labels, and recommended pathways as intended.

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Appendices

The following appendices provide the complete supporting tables used for indicator assessment, stakeholder mapping, and citizen-facing indicator selection.

Appendix A. 58-Indicator Assessment Table

58-indicator assessment table

Code	Meaning
N	National-scale threshold
R	Regional-scale threshold
Yes/No	Qualitative threshold
A	Directly calculable
B	Partially calculable
C	Potentially calculable later
D	Not calculable in the current thesis stack

Seq.	Performance	Criterion	Indicator	Threshold value	Threshold type	Reference source	Current calculability	Assessment basis	Source(s)
1	Energy	Consumption	Total consumption	> 0.5 GWh/year (R)	R	GSE official CER page: https://www.gse.it/servizi-per-te/autoconsumo/gruppi-di-autoconsumatori-e-comunita-di-energia-rinnovabile/comunit%C3%A0-energetiche-rinnovabili	A	annual + hourly building consumption tables	Already available in current thesis database/scripts

2	Energy	Consumption	Plurality of end users	Companies + Municipalities + Domestic	R	GSE official CER page: https://www.gse.it/servizi-per-te/autoconsumo/gruppi-di-autoconsumatori-e-comunita-di-energia-rinnovabile/comunit%C3%A0-energetiche-rinnovabili	B	building classification + territorial aggregation	Already available in current thesis database/scripts
3	Energy	Consumption	Consumption by sector	-		GSE official CER page: https://www.gse.it/servizi-per-te/autoconsumo/gruppi-di-autoconsumatori-e-comunita-di-energia-rinnovabile/comunit%C3%A0-energetiche-rinnovabili	A	residential / service / industrial / agricultural disaggregation	Already available in current thesis database/scripts
4	Energy	Consumption	Plurality of energy subject	Producer + Consumer + Prosumer	N	GSE official CER page: https://www.gse.it/servizi-per-te/autoconsumo/gruppi-di-autoconsumatori-e-comunita-di-energia-rinnovabile/comunit%C3%A0-energetiche-rinnovabili	B	spatial comparison of consumption and production roles	Already available in current thesis database/scripts; supporting modelling reference
5	Energy	Consumption	Energy intensity	< 107.8 Tep/M EUR (N)	national	Eurostat; PNIEC	C	needs energy vs economic-output denominator	Already available in current thesis database/scripts; RAEE2025-web: https://www.efficienzaenergetica.enea.it/vi-segnaliamo/rapporto-annuale-sull-efficienza-energetica-2025-schede-regionali.html
6	Energy	Production	Annual total production	-		GSE official CER page: https://www.gse.it/servizi-per-te/autoconsumo/gruppi-di-autoconsumatori-e-comunita-di-energia-rinnovabile/comunit%C3%A0-energetiche-rinnovabili	A	annual production table	Already available in current thesis database/scripts

7	Energy	Production	Energy mix	> 2 RES systems (R)	regional	GSE official CER page: https://www.gse.it/servizi-per-te/autoconsumo/gruppi-di-autoconsumatori-e-comunita-di-energia-rinnovabile/comunit%C3%A0-energetiche-rinnovabili	A	production by RES type	current thesis database/scripts maps ai_fonte to solar / wind / hydro / biomass / geothermal
8	Energy	Production	RES power capacity	> 6.5 kW pro-capita (N)	national	PNIEC	A	plant-level installed capacity field (`potenza`)	Already available in current thesis database/scripts
9	Energy	Production	Annual RES production	> 35% total production (R)	regional	GSE official CER page: https://www.gse.it/servizi-per-te/autoconsumo/gruppi-di-autoconsumatori-e-comunita-di-energia-rinnovabile/comunit%C3%A0-energetiche-rinnovabili	A	annual production by RES	Already available in current thesis database/scripts
10	Energy	Production	Share of RES in transport system	> 21.6% total consumption (N)	national	PNIEC	D	no transport-energy dataset	Already documented in the original protocol; no direct current data source identified in this table
11	Energy	Self-consumption	Self-consumption	> 70% total production (R)	R	GSE official CER page: https://www.gse.it/servizi-per-te/autoconsumo/gruppi-di-autoconsumatori-e-comunita-di-energia-rinnovabile/comunit%C3%A0-energetiche-rinnovabili	B	hourly consumption + hourly production + REC boundary logic	Already available in current thesis database/scripts; supporting modelling reference; RECON-web
12	Energy	Self-consumption	RES self-consumption	> 70% total RES production (R)	R	GSE official CER page: https://www.gse.it/servizi-per-te/autoconsumo/gruppi-di-autoconsumatori-e-comunita-di-energia-rinnovabile/comunit%C3%A0-energetiche-rinnovabili	B	same as above	Already available in current thesis database/scripts; supporting modelling reference; RECON-web

13	Energy	Self-consumption	Overproduction	< 30% total production (R)	R	GSE official CER page: https://www.gse.it/servizi-per-te/autoconsumo/gruppi-di-autoconsumatori-e-comunita-di-energia-rinnovabile/comunit%C3%A0-energetiche-rinnovabili	B	hourly production vs consumption	Already available in current thesis database/scripts
14	Energy	Independence	Energy dependency	< 30% total demand (R)	regional	WEC	B	hourly residual demand	Already available in current thesis database/scripts; supporting modelling reference
15	Energy	Security	Storage system	Yes/No	qualitative yes/no	WEC	D	no storage table	Already documented in the original protocol; no direct current data source identified in this table
16	Energy	Security	System resiliency	Yes/No	qualitative yes/no	WEC	D	no resilience metric or outage dataset	supporting contextual source; PELL-web: https://www.pell.enea.it/
17	Energy	Efficiency	Energy efficiency (Savings rate)	+0.8% per year	national	Eurostat; PNIEC	C	- need future production	Already available in current thesis database/scripts; RECON-web: https://recon.smartenergycommunity.enea.it/; RAEE2025-web: https://www.efficienzaenergetica.enea.it/vi-segnaliamo/rapporto-annuale-sull-efficienza-energetica-2025-schede-regionali.html
18	Economic	Income poverty	Absolute poverty	< 5.2% population ; family expenses 753.8 €/month	regional	ISTAT	C	Need spatial data; Absolute poverty rate = population in absolute poverty / total population	ISTAT-web: https://www.istat.it/notizia/basi-territoriali-e-variabili-censuarie/; ISTAT poverty report: https://www.istat.it/it/archivio/poverta
19	Economic	Income poverty	Poverty risk	< 20.3% population ; < 60% median income	national	Eurostat	C	Need spatial data; Poverty risk rate = population below 60% of median income / total population	ISTAT poverty report: https://www.istat.it/it/archivio/poverta; Eurostat at-risk-of-poverty: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:At-risk-of-poverty_rate

20	Economic	Energy poverty	Arrears on utility bills	< 4.5% population	national	EPOV	C	Need spatial data;	EPOV indicators: https://www.energypoverty.eu/indicator?primaryId=1466
21	Economic	Energy poverty	Inability to keep home warm	< 14.1% population	national	EPOV	C	Need spatial data; official energy-poverty / housing survey indicators	EPOV indicators: https://www.energypoverty.eu/indicator?primaryId=1461; Eurostat housing statistics: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Housing_statistics
22	Economic	Energy poverty	Access to electricity	> 95.4% population	national	ISTAT	C	Need spatial data; proxy possible via grid/cabin coverage	Already available in current thesis database/scripts; PELL-web: https://www.pell.enea.it/
23	Economic	Energy poverty	Energy prices	< 0.16-0.20 EUR/kWh (R)	regional	ARERA	B	external tariff data / RECON assumptions	ARERA-web: https://reporting.arera.it/SASVisualAnalytics/?reportUri=%2Freports%2Freports%2Fff58199d-f010-4cfd-a5d1-32c1d6359c05&sso_guest=true&reportViewOnly=true&reportContextBar=false&sas-welcome=false; RECON-web: https://recon.smartenergycommunity.enea.it/
24	Economic	Local development	Occupation rate	> 42.5% population (N)	national	ISTAT	B	employment table + census spatial allocation	Already available in current thesis database/scripts; ISTAT-web: https://www.istat.it/notizia/basi-territoriali-e-variabili-censuarie/
25	Economic	Local development	Local economic growth	+0.4% / year	national	ISTAT	C	Need spatial data;	ISTAT-web: https://www.istat.it/notizia/basi-territoriali-e-variabili-censuarie/
26	Economic	Technological innovation	Graduates rate	> 9.2% population	regional	ISTAT	C	Need spatial data;	ISTAT-web: https://www.istat.it/notizia/basi-territoriali-e-variabili-censuarie/

27	Economic	Technological innovation	Access to internet	> 75.1% population	national	ISTAT	C	Need spatial data;	supporting contextual source; ISTAT-web: https://www.istat.it/notizia/basi-territoriali-e-variabili-censuarie/
28	Economic	Economic inequality	Average income (of families)	31,608 EUR/year/family (R)	regional	ISTAT	B	official income statistics or local tax-income proxy	ISTAT-web: https://www.istat.it/notizia/basi-territoriali-e-variabili-censuarie/; ISTAT household income: https://www.istat.it/comunicato-stampa/condizioni-di-vita-e-reddito-delle-famiglie-anni-2024-2025/; MEF comune income data: https://www1.finanze.gov.it/finanze/analisi_stat/public/index.php?opendata=yes&search_class%5B0%5D=cCOMUNE; ISTAT A misura di Comune: https://www.istat.it/statistica-sperimentale/aggiornamento-degli-indicatori-del-sistema-informativo-a-misura-di-comune/; ISTAT Nota metodologica 2024: https://www.istat.it/wp-content/uploads/2022/12/Nota-metodologica-2024.pdf
29	Economic	Economic inequality	Inequality income distribution	< 6.3% population	national	ISTAT; Eurostat	C	official inequality statistics (S80/S20, Gini) from Istat	ISTAT disuguaglianza archive: https://www.istat.it/it/archivio/disuguaglianza; ISTAT household income 2024-2025: https://www.istat.it/comunicato-stampa/condizioni-di-vita-e-reddito-delle-famiglie-anni-2024-2025/; ISTAT redistribution of income 2025: https://www.istat.it/comunicato-stampa/la-redistribuzione-del-reddito-in-italia-anno-2025/; ISTAT income and living conditions report 2024: https://www.istat.it/wp-content/uploads/2024/05/REPORT-REDDITO-CONDIZIONI-DI-VITA_2023.pdf
30	Social	Healthcare	Life expectation / Oldness index	Oldness index < 231% (R); life expectancy from official demographic stats	regional	ISTAT	B	official demographic statistics by administrative territorial scale	ISTAT-web: https://www.istat.it/notizia/basi-territoriali-e-variabili-censuarie/; ISTAT A misura di Comune tables 2024: https://www.istat.it/it/files/2022/12/INDICE-DELLE-TAVOLE-STATISTICHE-2024.pdf; ISTAT Nota metodologica 2024: https://www.istat.it/it/files/2022/12/Nota-metodologica-2024.pdf; ISTAT regional socio-health indicators: https://www.istat.it/non-categorizzato/indicatori-socio-sanitari-regionali/; ISTAT speranza di vita archive: https://www.istat.it/?tag=speranza-vita
31	Social	Healthcare	Unmet medical needs	> 7.68 doctors / 10k inhabitants	national	Eurostat; ISTAT	C	official health survey statistics	Eurostat unmet medical needs metadata: https://ec.europa.eu/eurostat/cache/metadata/en/hlth_silc_01_esms.htm; Eurostat unmet needs news: https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20231211-1; ISTAT databases: https://www.istat.it/dati/banche-dati/
32	Social	Education	Education degree	University > 9%; Senior HS > 35%; Junior HS > 30%; Primary > 26%	regional	ISTAT	B	official census education attributes	ISTAT-web: https://www.istat.it/notizia/basi-territoriali-e-variabili-censuarie/; ISTAT permanent census data: https://dati-censimentipermanenti.istat.it/

33	Social	Comfort and safety home	Comfortably warm home	> 85% dwellers	national	EPOV; Eurostat	C	official survey-based housing comfort statistics	ISTAT housing and living conditions hearing: https://www.istat.it/wp-content/uploads/2024/04/AS_audizione_emergenza_abitativa_17_04_2024.pdf; ISTAT BES 2023: https://www.istat.it/wp-content/uploads/2024/04/Rapporto_BES_2023.pdf; Eurostat housing statistics: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Housing_statistics
34	Social	Comfort and safety home	Comfortably cool home	> 76% dwellers	national	ISTAT	C	official survey-based housing comfort statistics	Already available in current thesis database/scripts; ISTAT-web: https://www.istat.it/notizia/basi-territoriali-e-variabili-censuarie/; ISTAT occupied dwellings tables: https://www.istat.it/it/files/2024/06/Abitazioni-occupate-da-residenti-e-relativi-principali-tipi-di-servizi-per-comune.xlsx; ISTAT housing and living conditions hearing: https://www.istat.it/wp-content/uploads/2024/04/AS_audizione_emergenza_abitativa_17_04_2024.pdf
35	Social	Comfort and safety home	Maintenance state of buildings	Good > 84.6% (R)	regional	ISTAT Census	C	census housing/building condition statistics	Already available in current thesis database/scripts; ISTAT-web: https://www.istat.it/notizia/basi-territoriali-e-variabili-censuarie/; ISTAT occupied dwellings tables: https://www.istat.it/it/files/2024/06/Abitazioni-occupate-da-residenti-e-relativi-principali-tipi-di-servizi-per-comune.xlsx; ISTAT housing and living conditions hearing: https://www.istat.it/wp-content/uploads/2024/04/AS_audizione_emergenza_abitativa_17_04_2024.pdf
36	Social	Comfort and safety home	Housing deprivation	> 49.6 m2/occupant (R)	regional	Eurostat; ISTAT	B	building area/volume + dwelling allocation proxy plus official stats	ISTAT public transport local data: https://www.istat.it/it/archivio/274824; ISTAT urban mobility report: https://www.istat.it/it/files/2022/11/7.pdf; ISTAT ambiente urbano: https://www.istat.it/it/archivio/289224
37	Social	Mobility	Access to public transport	< 33.5% population (N)	national	ISTAT	C	official public-transport accessibility statistics	Eurostat transport statistics at regional level: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Transport_statistics_at_regional_level; ISTAT urban mobility report: https://www.istat.it/it/files/2022/11/7.pdf
38	Social	Mobility	Intermodality of transport system	-	Descriptive	ISTAT	C	official urban mobility / transport-system context	ISTAT BES 2023: https://www.istat.it/wp-content/uploads/2024/04/Rapporto_BES_2023.pdf; ISTAT participation archive: https://www.istat.it/it/archivio/partecipazione
39	Social	Local community	Sense of community	> 24.6 / 100 inhabitants	national	ISTAT BES	C	official wellbeing / perception surveys	Meeting0514; ISTAT participation archive: https://www.istat.it/it/archivio/partecipazione; ISTAT BES 2023: https://www.istat.it/wp-content/uploads/2024/04/Rapporto_BES_2023.pdf

40	Social	Local community	Citizen participation	> 23.8 / 100 inhabitants	national	ISTAT BES	C	official civic/participation statistics	Already available in current thesis database/scripts; ISPRA data portal: https://www.isprambiente.gov.it/it/banche-dati; ISPRA annuario ambientale: https://annuario.isprambiente.it/
41	Environmental	Water pollution	Hydroelectric withdrawal	< 47% total withdrawal (R)	regional	ISPRA	C	hydro plant dataset + external water statistics	ISPRA data portal: https://www.isprambiente.gov.it/it/banche-dati; SNPA indicatori ambientali: https://indicatoriambientali.isprambiente.it/
42	Environmental	Water pollution	Protection of water sources	Good > 39% (R)	regional	ISPRA	C	official water-body / protection status datasets	ISPRA data portal: https://www.isprambiente.gov.it/it/banche-dati; SNPA indicatori ambientali: https://indicatoriambientali.isprambiente.it/
43	Environmental	Water pollution	Water quality	> 130 aqueducts / 600k inhabitants	regional	ISPRA	C	official aqueduct / water-quality monitoring statistics	Already available in current thesis database/scripts; ENEA RECON / supporting energy-emission calculation reference; RAEE2025-web: https://www.efficienzaenergetica.enea.it/vi-segnaliamo/rapporto-annuale-sull-efficienza-energetica-2025-schede-regionali.html
44	Environmental	Air pollution	Total GHG emissions	< 41.6 kton/year	national	ISPRA	B	Can use consumption + production + emission factor to estimate electricity-related CO2	Already available in current thesis database/scripts; ENEA RECON / supporting energy-emission calculation reference; RAEE2025-web: https://www.efficienzaenergetica.enea.it/vi-segnaliamo/rapporto-annuale-sull-efficienza-energetica-2025-schede-regionali.html
45	Environmental	Air pollution	GHG emissions by sector	-40% / 10 yr (N)	national	ISPRA	B	sectoral consumption disaggregation exists	ISPRA air quality pages: https://www.isprambiente.gov.it/it/attivita/suolo-e-territorio/qualita-dellaria; ARPA Lombardia air quality: https://www.arpalombardia.it/temi-ambientali/aria/
46	Environmental	Air pollution	Annual level of PM10-PM2.5	PM10 < 40 μg/m³；PM2.5 < 25 μg/m³	regional	ISPRA; ARPA	C	official air-quality monitoring networks	Already available in current thesis database/scripts
47	Environmental	Land pollution	Land use	< 6.9% total area (R)	regional	CORINE Land Cover	B	building geometry and spatial polygons available	ISPRA Carta della Natura: https://www.isprambiente.gov.it/it/attivita/suolo-e-territorio/carta-della-natura; ISPRA biodiversità: https://www.isprambiente.gov.it/it/attivita/biodiversita

48	Environmental	Land pollution	Forest protection	> 38.5% total area (R)	regional	CORINE Land Cover	B	CLC	ISPRA biodiversità: https://www.isprambiente.gov.it/it/attivita/biodiversita; ISPRA Carta della Natura: https://www.isprambiente.gov.it/it/attivita/suolo-e-territorio/carta-della-natura
49	Environmental	Land pollution	Biodiversity protection	> 17.8% total (R)	regional	Natura 2000; ISPRA	B	official biodiversity / Natura 2000 / protected-area datasets	ISPRA Rapporto Rifiuti Speciali 2025: https://www.isprambiente.gov.it/it/pubblicazioni/rapporti/rapporto-rifiuti-speciali-edizione-2025; ISPRA Catasto rifiuti: https://www.isprambiente.gov.it/it/attivita/rifiuti-e-bonifiche/rifiuti/catasto-rifiuti
50	Environmental	Waste management	Special hazardous waste	< 152.6 ton/year (R)	regional	ISPRA	C	official waste statistics	ISPRA Rapporto Rifiuti Urbani 2024: https://www.isprambiente.gov.it/it/pubblicazioni/rapporti/rapporto-rifiuti-urbani-edizione-2024; ISPRA Catasto rifiuti: https://www.isprambiente.gov.it/it/attivita/rifiuti-e-bonifiche/rifiuti/catasto-rifiuti
51	Environmental	Waste management	Recycling rate	> 61.3% total waste (R)	regional	ISPRA	C	official municipal waste statistics, need spatial data	ISPRA Rapporto Rifiuti Urbani 2024: https://www.isprambiente.gov.it/it/pubblicazioni/rapporti/rapporto-rifiuti-urbani-edizione-2024; ISPRA Catasto rifiuti: https://www.isprambiente.gov.it/it/attivita/rifiuti-e-bonifiche/rifiuti/catasto-rifiuti
52	Environmental	Waste management	Landfill waste rate	< 9.8% total waste (R)	regional	GSE official CER page: https://www.gse.it/servizi-per-te/autoconsumo/gruppi-di-autoconsumatori-e-comunita-di-energia-rinnovabile/comunit%C3%A0-energetiche-rinnovabili	C	official municipal waste-treatment statistics; need spatial data	Already available in current thesis database/scripts; PELL-web: https://www.pell.enea.it/; Terna grid portal: https://www.terna.it/it/sistema-elettrico/rete
53	Territorial	Network	Contiguity of electric network	Yes/No	R	Terna; PELL	B	primary cabin mapping as proxy + official grid context	ISTAT urban mobility report: https://www.istat.it/it/files/2022/11/7.pdf; ISTAT ambiente urbano: https://www.istat.it/it/archivio/289224
54	Territorial	Network	Connectivity of the road network	-		ISTAT	C	official transport/mobility context	ISTAT public transport local data: https://www.istat.it/it/archivio/274824; ISTAT urban mobility report: https://www.istat.it/it/files/2022/11/7.pdf
55	Territorial	Network	Efficiency of public transport	< 12 min waiting (R)	regional	ISTAT	C	official local public-transport statistics	ISTAT ambiente urbano: https://www.istat.it/it/archivio/289224; ISTAT Rapporto Territorio 2020: https://www.istat.it/it/files//2020/07/7.pdf

56	Territorial	Network	Availability of safe cycling routes	> 1.5 m/inhab (N)	national	Fiab	C	official urban environment / cycling infrastructure statistics	P23; [ISTAT ambiente urbano](https://www.istat.it/it/archivio/289224); [ISTAT Rapporto Territorio 2020](https://www.istat.it/it/files//2020/07/7.pdf)
57	Territorial	Local aggregation	Territorial / municipal aggregation	Yes/No	qualitative yes/no	GSE official CER page	A	province / census / primary cabin mapping	P23; SQL1; SQL2; JSE
58	Territorial	Governance	Strategic territorial plans	Yes/No	qualitative yes/no	Regione Lombardia PTR	C	qualitative planning-document layer from official regional/municipal portals	P23; CiS; [Regione Lombardia PTR](https://www.regione.lombardia.it/wps/portal/istituzionale/HP/DettaglioRedazionale/servizi-e-informazioni/enti-e-operatori/territorio/governo-del-territorio/piano-territoriale-regionale-ptr/piano-territoriale-regionale-ptr); [Regione FVG territorial planning](https://www.regione.fvg.it/rafvg/cms/RAFVG/territorio-ambiente-paesaggio/pianificazione-gestione-territorio/)

Appendix B. Stakeholder-Indicator Mapping

Stakeholder-Indicator Mapping by Performance

Energy Performance

Seq.	Indicator	Criterion	Main usage	Main stakeholder	Short justification
1	Total consumption	Consumption	Planning, Benchmarking	Private Companies	Provides the baseline level of local energy demand and helps residents understand the scale of consumption that REC measures should respond to.
2	Plurality of end users	Consumption	Planning	Policy-making and Planning Entities	Supports planning authorities in identifying the diversity of demand-side actors and potential REC aggregation conditions.
3	Consumption by sector	Consumption	Planning, Monitoring	Policy-making and Planning Entities	Supports public planning by showing how energy demand is distributed across residential, tertiary, industrial, or public-service sectors.
4	Plurality of energy subject	Consumption	Planning	Policy-making and Planning Entities	Helps planning authorities understand the coexistence of consumers, producers, and prosumers when structuring REC roles.
5	Energy intensity	Consumption	Benchmarking	Policy-making and Planning Entities	Supports territorial benchmarking by comparing energy use with socio-economic activity across areas or sectors.
6	Annual total production	Production	Planning, Monitoring	Private Companies	Supports project developers and energy operators in assessing local production capacity, expected output, and generation-asset performance.
7	Energy mix	Production	Benchmarking, Representation	Policy-making and Planning Entities	Helps residents understand the composition of local energy sources and the relative role of renewable energy in the territory.
8	RES power capacity	Production	Planning, Benchmarking	Private Companies	Supports investors, developers, and energy-service actors in assessing installed capacity, production potential, and project sizing.
9	Annual RES production	Production	Monitoring, Representation	Citizens	Communicates the amount of renewable energy actually generated locally and makes local renewable output visible to residents.

10	Share of RES in transport system	Production	Planning	Policy-making and Planning Entities	Supports public authorities in linking renewable energy use with transport policy and low-carbon mobility planning.
11	Self-consumption	Self-consumption	Monitoring, Representation	Citizens	Shows how much locally produced energy is used within the community and directly explains a core REC benefit to residents.
12	RES self-consumption	Self-consumption	Monitoring, Representation	Citizens	Shows how much locally generated renewable energy is retained locally and translates renewable self-consumption into a citizen-readable benefit.
13	Overproduction	Self-consumption	Monitoring, Representation	Policy-making and Planning Entities	Supports public planning decisions on surplus production, storage needs, grid interaction, and local energy management.
14	Energy dependency	Independence	Benchmarking, Representation	Citizens	Explains the extent to which the area depends on external energy supply and helps residents understand local energy autonomy.
15	Storage system	Security	Planning, Operations	Private Companies	Supports operational actors in evaluating storage capacity, balancing potential, and optimization of REC energy flows.
16	System resiliency	Security	Planning, Benchmarking	Policy-making and Planning Entities	Supports public planning by assessing whether the local energy system can withstand disruptions and maintain service continuity.
17	Energy efficiency (Savings rate)	Efficiency	Benchmarking, Representation	Citizens	Translates energy savings or efficiency improvements into household-level and community-level benefits that residents can understand.

Economic Performance

Seq.	Indicator	Criterion	Main usage	Main stakeholder	Short justification
18	Absolute poverty	Income poverty	Planning, Benchmarking	Policy-making and Planning Entities	Supports public authorities in identifying vulnerable groups and targeting REC-related social or energy-poverty measures.

19	Poverty risk	Income poverty	Planning, Benchmarking	Policy-making and Planning Entities	Supports policy actors in assessing broader poverty exposure and aligning REC measures with social-inclusion objectives.
20	Arrears on utility bills	Energy poverty	Monitoring, Representation	Citizens	Directly reflects household difficulty in paying energy-related bills and is highly relevant for citizen-facing energy-poverty assessment.
21	Inability to keep home warm	Energy poverty	Monitoring, Representation	Citizens	Connects household thermal deprivation with comfort, affordability, and vulnerability in a way that is directly understandable to residents.
22	Access to electricity	Energy poverty	Planning, Benchmarking	Policy-making and Planning Entities	Supports public authorities in comparing basic access to energy services and identifying energy-inclusion gaps.
23	Energy prices	Energy poverty	Planning, Representation	Citizens	Represents a direct household concern because electricity prices affect energy expenditure and perceived economic benefits from REC participation.
24	Occupation rate	Local development	Benchmarking, Planning	Policy-making and Planning Entities	Supports policy and planning actors in understanding the employment context of the territory and broader local development conditions.
25	Local economic growth	Local development	Benchmarking, Planning	Policy-making and Planning Entities	Supports public authorities in evaluating whether REC development aligns with local economic performance and territorial development goals.
26	Graduates rate	Technological innovation	Benchmarking, Planning	Education and Research	Represents local human-capital conditions and helps education and research actors assess knowledge capacity and innovation potential.
27	Access to internet	Technological innovation	Planning, Representation	Citizens	Indicates whether residents can access digital energy information, online platforms, and participation tools.
28	Average income (of families)	Economic inequality	Benchmarking, Planning	Policy-making and Planning Entities	Supports public authorities in evaluating affordability, distributional effects, and the social targeting of REC benefits.
29	Inequality income distribution	Economic inequality	Benchmarking, Planning	Policy-making and Planning Entities	Supports policy actors in assessing income disparities and the equity implications of REC strategies.

Social Performance

Seq.	Indicator	Criterion	Main usage	Main stakeholder	Short justification
30	Life expectation / Oldness index	Healthcare	Benchmarking, Planning	Health and Public Services	Supports health and public-service actors in understanding demographic vulnerability and service-demand conditions.
31	Unmet medical needs	Healthcare	Planning, Benchmarking	Health and Public Services	Identifies barriers to health services and supports public-service actors in locating vulnerable populations.
32	Education degree	Education	Benchmarking, Planning	Education and Research	Represents educational attainment and helps education and research actors assess awareness, capacity, and participation potential.
33	Comfortably warm home	Comfort and safety home	Monitoring, Representation	Citizens	Directly reflects whether households can maintain adequate warmth and connects energy conditions with everyday comfort.
34	Comfortably cool home	Comfort and safety home	Monitoring, Representation	Citizens	Directly reflects whether households can maintain adequate cooling and links REC-related energy measures with climate-adaptation concerns.
35	Maintenance state of buildings	Comfort and safety home	Planning, Benchmarking	Policy-making and Planning Entities	Supports planning authorities in identifying building-condition constraints that affect retrofit needs and energy-efficiency priorities.
36	Housing deprivation	Comfort and safety home	Planning, Representation	Citizens	Captures inadequate housing conditions and helps identify households that may need targeted social or energy support.
37	Access to public transport	Mobility	Planning, Representation	Citizens	Represents everyday accessibility and helps residents understand links between local services, mobility, and territorial equity.
38	Intermodality of transport system	Mobility	Planning, Benchmarking	Policy-making and Planning Entities	Supports public planning by assessing the integration of transport modes within sustainable mobility systems.
39	Sense of community	Local community	Representation, Benchmarking	Citizens	Captures social cohesion and trust conditions that influence citizen participation and collective action in RECs.
40	Citizen participation	Local community	Representation, Monitoring	Citizens	Measures public involvement and directly reflects the co-decision-making role of citizens in REC development.

Environmental Performance

Seq.	Indicator	Criterion	Main usage	Main stakeholder	Short justification
41	Hydroelectric withdrawal	Water pollution	Planning, Benchmarking	Policy-making and Planning Entities	Supports environmental planning by assessing water-resource pressure associated with energy production.
42	Protection of water sources	Water pollution	Planning, Benchmarking	Policy-making and Planning Entities	Supports public environmental governance by indicating the protection status of water sources.
43	Water quality	Water pollution	Monitoring, Benchmarking	Health and Public Services	Supports health and public-service actors by describing environmental conditions that may affect public health and service needs.
44	Total GHG emissions	Air pollution	Monitoring, Benchmarking	Policy-making and Planning Entities	Translates the climate impact of local energy use into an environmental benefit indicator that residents can understand.
45	GHG emissions by sector	Air pollution	Benchmarking, Planning	Policy-making and Planning Entities	Supports public authorities in identifying sector-specific mitigation priorities and monitoring climate-policy performance.
46	Annual level of PM10-PM2.5	Air pollution	Monitoring, Benchmarking	Health and Public Services	Supports public-health monitoring by indicating local exposure to PM10 and PM2.5 pollution.
47	Land use	Land pollution	Planning, Benchmarking	Policy-making and Planning Entities	Supports spatial planning by identifying land-use pressures and constraints for renewable-energy integration.
48	Forest protection	Land pollution	Planning, Benchmarking	Policy-making and Planning Entities	Supports environmental planning by identifying forest-protection conditions and territorial conservation priorities.
49	Biodiversity protection	Land pollution	Planning, Benchmarking	Policy-making and Planning Entities	Supports environmental governance by assessing biodiversity-protection conditions and potential territorial trade-offs.
50	Special hazardous waste	Waste management	Monitoring, Planning	Health and Public Services	Supports public-service and environmental-health actors in monitoring hazardous-waste risks and sensitive local conditions.

51	Recycling rate	Waste management	Monitoring, Representation	Policy-making and Planning Entities	Supports local environmental policy and waste-management benchmarking within the broader sustainability context.
52	Landfill waste rate	Waste management	Benchmarking, Monitoring	Policy-making and Planning Entities	Supports public authorities in benchmarking landfill dependence and identifying waste-management priorities.

Territorial Performance

Seq.	Indicator	Criterion	Main usage	Main stakeholder	Short justification
53	Contiguity of electric network	Network	Planning	Policy-making and Planning Entities	Supports planning authorities in assessing whether the electricity network is spatially suitable for REC configuration.
54	Connectivity of the road network	Network	Planning, Benchmarking	Policy-making and Planning Entities	Supports territorial planning by assessing accessibility, infrastructure connectivity, and service provision conditions.
55	Efficiency of public transport	Network	Benchmarking, Planning	Policy-making and Planning Entities	Supports public mobility planning by evaluating the performance of public transport services.
56	Availability of safe cycling routes	Network	Planning, Representation	Policy-making and Planning Entities	Supports local planning by identifying sustainable-mobility infrastructure and accessibility conditions.
57	Territorial / municipal aggregation	Local aggregation	Planning	Policy-making and Planning Entities	Supports governance and planning by assessing whether municipalities or areas can be aggregated for REC implementation.
58	Strategic territorial plans	Governance	Planning	Policy-making and Planning Entities	Supports public authorities in aligning REC development with existing territorial plans and governance frameworks.

Appendix C. Final Citizen-Facing Prototype Indicators

Final Prototype Indicators

No.	Indicator	Performance	Threshold value	Threshold type	Assessment method	Reference source	Current calculability	Why / short reason	Source(s)	Citizen-facing meaning	Possible representation
1	Total consumption	Energy Performance	> 0.5 GWh/year	Regulatory threshold	Assess whether the annual electricity consumption of the EC is greater than 0.5 GWh.	GSE official CER page: https://www.gse.it/servizi-per-te/autoconsumo/gruppi-di-autoconsumatori-e-comunita-di-energia-rinnovabile/comunit%C3%A0-energetiche-rinnovabili	A	The current scripts can construct building-scale annual and hourly electricity consumption.	Already available in current thesis database	How much electricity the area or community needs each year; this is the demand baseline for understanding renewable coverage and potential bill savings.	Demand baseline card; annual consumption chart; map by building or area.
2	RES power capacity	Energy Performance	> 6.5 kW per capita	National target threshold	Assess whether renewable installed capacity per capita reaches the threshold.	PNIEC	A	The plants layer directly contains installed power (potenza).	Already available in current thesis database	How much renewable energy capacity already exists, or could potentially exist, in the local area; comparable to PV potential in citizen solar portals.	Capacity card; map layer; building or REC-area potential summary.

3	Annual RES production	Energy Performance	> 35% of total production	Regulatory threshold	Calculate RES electricity production divided by total electricity production; values above 35% are considered compliant.	GSE official CER page: https://www.gse.it/servizi-per-te/autoconsumo/gruppi-di-autoconsumatori-e-comunita-di-energia-rinnovabile/comunit%C3%A0-energetiche-rinnovabili	A	Yearly production can be directly aggregated by RES type.	Already available in current thesis database	How much local green electricity the community produces each year; one of the most direct renewable-benefit indicators.	Annual RES production card; bar chart; scenario comparison.
4	Energy mix	Energy Performance	> 2 RES systems	Regulatory threshold	Assess whether more than two renewable energy systems are present, such as PV, hydro, or biomass.	GSE official CER page: https://www.gse.it/servizi-per-te/autoconsumo/gruppi-di-autoconsumatori-e-comunita-di-energia-rinnovabile/comunit%C3%A0-energetiche-rinnovabili	A	SQL2 maps ai_fonte to solar, wind, hydro, biomass, and geothermal sources.	Already available in current thesis database	Which renewable energy sources are present locally; this helps citizens form a readable community energy profile.	Donut chart; energy-source badges; map filter by RES type.
5	Self-consumption	Energy Performance	> 70% of total production	Regulatory threshold	Calculate locally self-consumed electricity divided by total electricity production; values above 70% are considered compliant.	GSE official CER page: https://www.gse.it/servizi-per-te/autoconsumo/gruppi-di-autoconsumatori-e-comunita-di-energia-rinnovabile/comunit%C3%A0-energetiche-rinnovabili	B	It can be estimated through hourly matching, but the REC aggregation or sharing boundary must be defined.	Already available in current thesis database; RECON-web	How much electricity produced by the community is actually used locally; a core citizen-facing REC benefit.	Percentage card; daily or hourly matching curve; baseline vs REC scenario.

6	RES self-consumption	Energy Performance	> 70% of total RES production	Regulatory threshold	Calculate locally self-consumed RES electricity divided by total RES production; values above 70% are considered compliant.	GSE official CER page: https://www.gse.it/servizi-per-te/autoconsumo/gruppi-di-autoconsumatori-e-comunita-di-energia-rinnovabile/comunit%C3%A0-energetiche-rinnovabili	B	It can be estimated, but hourly RES production must be matched with local electricity load.	Already available in current thesis database; RECON-web	How much locally generated green electricity is actually used locally; this highlights the renewable benefit more directly than general self-consumption.	Renewable self-consumption card; RES matching chart; scenario comparison.
7	Overproduction	Energy Performance	< 30% of total production	Regulatory threshold	Calculate surplus electricity exported or unused locally divided by total production; values below 30% are considered compliant.	GSE official CER page: https://www.gse.it/servizi-per-te/autoconsumo/gruppi-di-autoconsumatori-e-comunita-di-energia-rinnovabile/comunit%C3%A0-energetiche-rinnovabili	B	Hourly arrays are available for estimating time-series surplus, but scenario and aggregation rules are still required.	Already available in current thesis database	Whether too much local green electricity is not used locally; this can be translated as surplus electricity.	Surplus electricity card; hourly surplus curve; suggested action note.
8	Energy dependency	Energy Performance	< 30% of total demand	Regulatory threshold	Calculate the demand not covered by local production divided by total demand; values below 30% are considered compliant.	WEC	B	It can be derived from the production-consumption balance, but a matching logic is required.	Already available in current thesis database	How much electricity demand still depends on the external grid; suitable for expressing community energy independence.	Dependency score; covered vs uncovered demand chart; scenario comparison.

9	Energy prices	Economic Performance	< 0.16-0.20 EUR/kWh	Reference threshold	Assess whether the electricity price is below the reference value; it can also be used as an economic input.	ARERA	B	The current SQL database does not include a tariff table, but ARERA and ENEA RECON can provide price inputs.	Already available in current thesis database; ARERA-web; RECON-web	The economic input most directly perceived by residents; it is also the basis for calculating bill savings or cost reduction.	Tariff assumption card; editable price input; bill-saving scenario input.
10	Total GHG emissions	Environmental Performance	< 41.6 kton/year	National target threshold	Calculate annual total greenhouse gas emissions; values below 41.6 kton/year are considered compliant.	ISPRA; PNIEC	B	Electricity-related CO_2 can be estimated from consumption, production, and emission factors, but this is not measured total GHG across all sectors.	Already available in current thesis databaseRECON-SUE; RAEE2025-web	The emission-reduction effect of the community or area; an environmental co-benefit that citizens can easily understand.	CO_2 emissions or avoided CO_2 card; baseline vs REC comparison; environmental benefit label.

Contextual Indicators Not Selected for the First Prototype

English version structured with the same fields as the final prototype indicator set.

No.	Indicator	Performance	Threshold value	Threshold type	Assessment method	Reference source	Current calculability	Why / short reason	Source(s)	Citizen-facing meaning	Possible representation

1	Arrears on utility bills	Economic Performance	< 4.5% population	National threshold	Calculate the share of the population in arrears on utility bills; values below 4.5% are considered compliant.	EPOV	C	Relevant to household burden and energy poverty, but mainly derived from survey-based or official statistics rather than current REC operational data.	Already available in current thesis database; EPOV indicators	Shows how many households struggle to pay energy-related bills, making visible a direct dimension of energy affordability stress.	Energy-poverty context card; municipality comparison; vulnerability background panel.
2	Inability to keep home warm	Economic Performance	< 14.1% population	National threshold	Calculate the share of the population unable to keep their home adequately warm; values below 14.1% are considered compliant.	EPOV	C	Very important for energy poverty assessment, but better suited to a vulnerability-context layer than to the first energy-flow-focused prototype.	Already available in current thesis database; EPOV indicators; Eurostat housing statistics	Shows winter thermal hardship experienced by households and links energy conditions to everyday well-being.	Thermal-vulnerability context card; seasonal comfort comparison; social-risk layer.
3	Comfortably warm home	Social Performance	> 85% dwellers	National threshold	Calculate the share of dwellers who consider their home warm enough in winter; values above 85% are considered compliant.	EPOV	C	Closely related to lived residential comfort, but current local REC-scale direct data are lacking.	Already available in current thesis database; ISTAT housing and living conditions; ISTAT BES 2023; Eurostat housing statistics	Expresses whether residents feel adequately warm at home during winter, connecting housing comfort with social and energy conditions.	Comfort indicator card; winter well-being panel; housing-comfort context layer.
4	Comfortably cool home	Social Performance	> 76% dwellers	National threshold	Calculate the share of dwellers who consider their home cool enough in summer; values above 76% are considered compliant.	ISTAT / survey-based reference	C	Can support a future social-comfort layer, but current data are survey-based and not available at a useful REC-scale resolution.	Already available in current thesis database; ISTAT housing and living conditions; ISTAT BES 2023; Eurostat housing statistics	Expresses summer thermal comfort and can reveal heat-related vulnerability in residential settings.	Summer comfort card; heat-vulnerability context layer; seasonal comparison chart.

5	Citizen participation	Social Performance	> 23.8 per 100 inhabitants	National threshold	Calculate the share of residents participating in public affairs, community activities, or social organizations; values above 23.8 per 100 inhabitants are considered compliant.	ISTAT	C	Important for governance and collective capacity, but not a metric directly calculable from the current operational REC scripts.	Already available in current thesis database; Meeting0514; ISTAT participation archive; ISTAT BES 2023	Shows the level of civic engagement that may support collective action, participation, and community governance.	Participation context card; civic-engagement panel; governance-readiness layer.
6	Annual level of PM10-PM2.5	Environmental Performance	PM10 < 40 µg/m³; PM2.5 < 25 µg/m³	Regional threshold	Calculate the annual average concentration of PM10 and PM2.5; values below the limit are considered compliant.	Eurostat	C	Relevant to health and environmental quality, but dependent on external monitoring-network data and therefore better treated as environmental context.	Already available in current thesis database; ISPRA air quality pages; ARPA Lombardia air quality	Shows local air-quality conditions that citizens can directly relate to health, exposure, and quality of life.	Air-quality context card; pollution-status badge; territorial background layer.
7	Recycling rate	Environmental Performance	> 61.3% total waste	Regional threshold	Calculate recycled waste divided by total waste; values above 61.3% are considered compliant.	ARPA; ISPRA	C	Easy for citizens to understand, but its direct relationship with REC energy flows is weaker than the indicators selected for the first prototype.	Already available in current thesis database; ISPRA Rapporto Rifiuti Urbani 2024; ISPRA Catasto rifiuti	Represents local circular-economy performance and broader community responsibility beyond energy alone.	Circular-economy context card; sustainability badge; municipality comparison view.