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Master's Thesis

An Interactive Platform for Energy Community Decision Support: Stakeholder-Driven Dashboard Design and Scenario Analysis in Italy

Supervisors:

Guglielmina Mutani

Andrea Ajmar

Candidate:

Mohammad Hossein Ahvar

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Abstract

This thesis investigates how digital tools can assist Renewable Energy Communities (RECs) in planning and decision-making. As interest in decentralized energy systems grows, particularly those based on solar energy, local communities are increasingly engaging in energy production and management. For such initiatives to be effective, there is a clear need for practical tools that present complex energy data in a way that is both accurate and easy to interpret.

The research focuses on the design of a digital platform that brings together spatial analysis, data visualization, and stakeholder needs. The platform was developed using GIS technologies and Business Intelligence methods, with particular attention to the different roles and expectations of local authorities, citizens, utility providers, and private investors. Through an analysis of these roles, a series of indicators were selected, such as levels of local energy use, self-sufficiency, and financial impact, reflecting the priorities of those involved.

Based on real data for energy production and consumption, the thesis explores several sharing scenarios to better understand how different configurations influence outcomes at the community level. These explorations reveal how an interactive and well-structured dashboard can help users grasp key energy trends, evaluate possible choices, and engage more directly in energy-related decisions.

The work highlights the importance of designing tools that are not only technically reliable but also understandable for non-experts. By encouraging participation and transparency, such tools can support a more inclusive and locally grounded energy transition.

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Chapter 1: Introduction

1.1 Background and Context

The way energy is produced and managed is changing very fast, throughout the world. This change is basically caused by the need to decrease greenhouse gas emissions, tackle climate change challenges, and move away from fossil fuel dependence. In this context, Renewable Energy Communities are becoming such a crucial part of the shift toward cleaner and more local energy systems. These communities usually rely on solar power and bring together citizens, municipalities, private stakeholders like banks and investors, to take part in both energy production and decision-making.

What makes Renewable Energy communities stand out is their local approach. Instead of depending just on centralized energy providers, these communities allow people and institutions especially at the local scale to have responsibility for how energy is generated, consumed, and distributed. Considering the fact that, the practical management of such systems is not apparently easy. Energy data can be huge and dense, very technical, and difficult to interpret and understand, without proper tools. For Renewable Energy communities to function effectively and properly, there is a growing need for systems that not only provide accurate information but also make it understandable and useful for a wide audience, in order to inform all stakeholders to give them valuable insights.

1.2 Problem Statement

Despite the fact that there is recent progress in developing energy-related digital platforms and interfaces, many of them fail to meet the needs of both technical users and everyday citizens. Some tools are very detailed, make it hard to use without expert and specific knowledge, while others are very simplified and lack the deep need for real territorial planning or analysis. This disconnection makes a barrier to meaningful engagement and weakens the potential of Renewable Energy Communities as inclusive, data-informed communities.

To support local planning, participation and cooperation, it is crucial to design and develop interfaces that make complex data easier to engage with. These tools have to be able to engage various groups, local administrators, citizens, utility managers, investors and private companies, each of these groups of stakeholders have different interests and levels of expertise and understanding of energetic data. Without this flexibility, even well-intentioned and professionally designed digital platforms may have difficulties to be effective for the real world challenges.

1.3 Objectives of the Thesis

The aim of this thesis is to design and test interactive visualization tools that help Renewable Energy Communities understand and use their energy data more effectively. The work focuses on bridging the gap between technical content and real-world usability. In particular, the objectives are:

- To build interfaces that support planning, energy monitoring, and collaborative decision-making within RECs;
- To evaluate how well these tools serve different users in terms of clarity, accessibility, usability and relevance;
- To identify practical design approaches and methodologies that make complex energy information more manageable in the context of local governance and decentralized systems.

1.4 Research Questions

To guide the research, the following questions are addressed:

- How can interactive interfaces be designed to support the diverse needs of stakeholders involved in energy community planning?
- What are the strengths and limitations of different visualization approaches in terms of usability, interactivity, and data comprehension?
- Which interface design strategies, as well choosing appropriate indicators and the way to visualize them, are most effective for specific stakeholder groups such as policymakers, citizens, utilities, and investors?

Chapter 2: Literature Review

2.1 Energy Transition and the Role of Energy Communities

"Energy production based on fossil sources is no longer sustainable for humankind" (Bilardo et al., 2020, p. 7), and awareness of the need for change is growing globally. The European Union has set ambitious renewable energy targets in response to the Paris Agreement, aiming for at least a 32% share of renewable energy sources (RES) by 2030. In this context, energy transition requires a shift from centralized energy systems toward decentralized renewable energy production (Bilardo et al., 2020). As (Mutani et al., 2020, p. 346) emphasize, "the transformation from the current energy system to a decentralized renewable energy system requires the transformation of communities into energy-producing communities." Community

Energy (CE) offers a viable solution to accelerate this transition by empowering local actors to take part in energy production and consumption.

Energy communities which are cooperative and partnership-based, and also non-profit organizations, bring together residents, municipalities, provinces, and private stakeholders such as investors, to collectively produce, distribute, and manage renewable energy (Mutani et al., 2020). Their role in the energy transition is highly important, as they make it easier to decentralize energy production, improve self-sufficiency, and promote clean energy adaptation, reducing the dependence on just fossil fuels (Bilardo et al., 2020). Recent Research shows that Energy communities could contribute to decrease the energy costs, with reported savings of about 20-30%, while also improving local engagement and sustainable development (Mutani et al., 2022). In order to make energy communities successful, it is not just about policies and technology, it also depends on how effectively they can monitor and analyze their energy dynamics. Many of the recent studies highlight that key indicators like the Self Sufficiency Index and Self-Consumption Index are highly important in order to assess energy performance, to ensure the economic and technical feasibility of Energy communities (Mutani et al., 2023). In order to support decision-making, clear, understandable and accessible data visualization platforms like dashboards are very important, to help different stakeholders, interpret energy consumption and production patterns and assess renewable energy contributions.

2.2 Data Collection and Standardization in Energy Planning

The success of energy planning and visualization depends largely on having high-quality, consistent, and compatible data. But one of the biggest challenges in this field is the **fragmentation of energy datasets**. These datasets often come from different sources, each with its own format, making it difficult to integrate and analyze them effectively (Mahama et al., 2020). On top of that, energy metrics are reported **inconsistently at different administrative levels**, making comparisons and decision-making even more complicated (Shyam & Kanakasabapathy, 2017).

To tackle these issues, the European Union has introduced a structured validation methodology aimed at improving the reliability and consistency of renewable energy data. This approach addresses key concerns such as technical accuracy and to track socioeconomic impacts, in order to ensure the alignment and coherency with policies and international frameworks (Bilardo et al., 2020). Also, making the data harmonize can help to bring together datasets from multiple sources, then can help to solve problems related to mismatched timestamps, missing data, and the methods that suffer from inconsistent measurements (Saputra et al., 2024).

One of the biggest problems in energy data standardization is interpretability of the data, in other words, the ability of different energy platforms to communicate and integrate data seamlessly. Without standardization of the approaches for energy consumption and production of the data across regions, building large-scale forecasting models and conducting meaningful comparative studies becomes difficult (Hanžel et al., 2024). To address this, researchers have proposed using **semantic data models** and **RDF knowledge graphs**, which create a shared analytical framework for processing datasets from different regions and energy systems (Hanžel et al., 2024). However, implementing these solutions at scale is still a challenge, especially since energy data must be synchronized across smart grids, sensor networks, and policy-driven data repositories (Reif et al., 2023).

To conclude, defining some frameworks and approaches that are able to ensure standardized and high quality energy data is crucial for precise, and useful energy data visualization and also decision-making. Without clear frameworks of integration, data governance, visualization tools can not show the real trends, leading to misleading conclusions and results (Bilardo et al., 2020). As the energy transition increases, automated data harmonization and interoperability of the real-time solutions will play a fundamental role in making a more data-driven, reliable approach to urban and energy planning (Strasser et al., 2023).

2.3 Data Visualization in Energy Planning

As energy systems are becoming more complex to understand, data visualization approaches are becoming crucial tools for having rapid and useful assessment, which leads to better decision-making in energy planning (Abdelalim et al., 2017). Due to the growing number of smart grids and progressed measurement systems, the amount of available energy data has increased, making it important to process and present this information in a clear, effective way.

With renewable energy systems such as photovoltaic systems and wind turbines playing a bigger role in the energy mix, there's a growing need for more data visualizations platforms, which are granular, time-sensitive, that can demonstrate seasonal variations and system fluctuations and their dynamics. (Wilson, 2016). At the same time, different models of energy systems are largely used to engage different stakeholders, analyze different types of scenarios, and reshape energy policies, highlighting the crucial role of data visualization in energy transitions (Plazas-Niño et al., 2024).

2.4 Decision Support Systems (DSS) for Energy Data-Driven Decision-Making

A key aspect of Decision Support Systems (DSS) in energy planning is data visualization, which transforms complex datasets into clear, meaningful graphics. By integrating DSS with Geographic Information Systems (GIS) and Business Intelligence (BI) tools, energy planners can gain both spatial and temporal insights into energy consumption, production, and distribution. Ali et al. (2020) highlight that GIS-based DSS allow for multi-scale energy analysis, making it possible to assess energy demand at municipal, regional, and national levels. Similarly, Mattah et al. (2020)emphasize that BI-driven DSS enhance energy management with features like predictive analytics, automated dashboards, and performance monitoring..

In conclusion, decision support systems play a vital role in the interpretation of energy data, providing geospatial analysis, real-time monitoring, and predictive modeling to support renewable energy planning. However, ensuring data standardization, improving interoperability, and integrating emerging technologies remain key challenges in unlocking their full potential.

2.5 GIS and BI Tools in Decision-Making for Renewable Energy

2.5.1 Geographic Information Systems (GIS) in Energy Planning

Geographic Information Systems (GIS) have become increasingly central for the renewable energy planning, especially because of their good capacity to combine different layers of spatial and non-spatial data. Their usefulness lies not only in mapping resources but in supporting complex decisions around where and how renewable energy infrastructure should be developed.

In the context of solar and wind energies, GIS allows planners to assess local conditions by integrating data such as solar radiation, wind speed, land use regulations, and grid availability. These layers, when viewed together, offer a clearer and better understanding of where installations would be most effective and least disruptive (Yoshida et al., 2024). Importantly, GIS is not just about location—it's also a means of balancing competing interests: environmental, technical, and social.

To improve decision making in this area, GIS is often combined with Multi Criteria Decision Making (MCDM) approaches. These allow for better evaluations that take into account not just physical geography but also factors like land value, ecological sensitivity, and proximity to demand centers. In the work by Alvarado et al. (2024), for example, such integration helped identify optimal sites that aligned with both technical feasibility and environmental protection goals.

Beyond its role in site selection, GIS is now being applied to broader questions of urban energy policy and sustainability. Kimura and Yamagata (2025) shows that how spatial analysis tools can support scenario planning in cities by exploring how interventions—such as increasing green space or retrofitting buildings—might influence carbon emissions and energy demand. This type of work links GIS with strategic planning and long-term climate goals.

Another area where GIS proves valuable is in the coordination of regional energy systems. A study by Guerrero et al. (2024) illustrates how spatial data on energy supply, demand, and socio-economic characteristics can be brought together to manage multi-source energy networks more efficiently. Their findings suggest that regional energy strategies benefit from a spatially informed approach, especially when dealing with diverse energy sources and infrastructure constraints.

2.5.2 Business Intelligence (BI) for Energy Data Management and Visualization

In today's energy landscape, Business Intelligence (BI) tools have become indispensable in order to handle the growing volume of both real-time and historical energy data. These platforms make it possible to visualize complex information through interactive dashboards, track key performance indicators, and even generate predictive insights. Among them, Google Looker Studio, Power BI, Esri experience builder, act as specific accessible tools, offering users the ability to monitor electricity, heating, and cooling usage with impressive frequency and clarity (Nguyen, 2023).

One of the strengths of BI dashboards is their capacity to make sense of consumption patterns and support smarter decision-making. Real-time monitoring doesn't just improve operational efficiency, it also helps detect irregularities early on, offering policymakers and planners a practical way to evaluate the financial viability of renewable energy initiatives and stay on track with decarbonization goals (Almeida et al., 2024). In industrial fields, BI tools are often linked with IoT sensor networks, giving businesses a powerful means to manage their energy use and reduce waste across systems (Kowalski et al., 2024).

So, these tools aren't without their limitations. Integrating data from different sources can be tricky, especially when the information arrives in inconsistent formats or contains gaps. This kind of fragmentation can slow down analysis and complicate integration with existing energy management systems (Ajax et al., 2025). On top of that, some users remain hesitant, often due to unclear outputs or a lack of tailored recommendations that they are able to work in them. To fully use of the potential of BI in energy planning, more effort is needed to improve interoperability, and design interfaces that speak the user's language, making insights not just available, but actionable and useful.

2.6 Best Practices in Renewable Energy Data Visualization and Scenario Modeling

Effective renewable energy planning increasingly depends on advanced visualization tools and interactive decision-support platforms. This section reviews selected studies that have successfully integrated Geographic Information Systems (GIS), Business Intelligence (BI), and Decision Support Systems (DSS) into intuitive, interactive interfaces. These examples have inspired the design of the proposed interface by illustrating practical solutions for scenario analysis, clear spatial-temporal data visualization, KPI-driven assessment, and effective policymaker engagement. The following table summarizes these inspirations, highlighting their relevance to the intended renewable energy planning interface developed in this thesis.

Author(s) & Year	Main Issue	Key Achievements	Specific Focus	Main Idea	Scale & Context	Relevance to Interface Development
Mutani et al. (2021)	Assessing the technical-economic feasibility of a Renewable Energy Community (REC)	Evaluated REC performance through hourly energy balance, cost-benefit analysis, and incentive schemes	Energy communities, PV-storage integration, REC policy framework, SSI & SCI metrics	Uses hourly energy flow analysis to optimize REC self-consumption and policy incentives	Municipal Scale (Villar Pellice, Italy)	Inspired by hourly energy performance metrics (SCI, SSI, Overproduction, Uncovered Demand), useful for real-time and scenario-based REC analysis
Pammi et al. (2023)	Difficulty in analyzing long-term renewable energy data for solar & wind planning	Created an interactive GIS-based dashboard integrating Global Horizontal Irradiance (GHI), Direct Normal Irradiance (DNI), and Wind Power (WP)	Renewable energy profiling, geospatial visualization, scenario analysis	Linked time-series & spatial analysis and interactive maps for energy planning	Global scale	Scenario-based analysis of energy production and demand, integrating spatial and temporal data. Ability to simulate virtual solar installations, adjust panel placements, and estimate energy generation under different conditions. Demand-supply comparison to assess energy balance at municipal, regional, and national levels.
Diaz et al. (2021)	Difficulty in visualizing uncertainty in renewable energy potential assessment	Created an interactive GIS-based dashboard to compare seven renewable energy scenarios using spatial and statistical visualizations	Uncertainty analysis in wind & solar energy forecasting, GIS-based energy mapping, scenario exploration	Uses GIS and parallel coordinate plots to analyze renewable energy potential under different constraints	National Scale (U.S.)	Scenario-based renewable energy visualization, uncertainty representation, and GIS-based energy potential mapping for policymakers

Ruggieri et al. (2023)	Assessing the economic feasibility and energy self-sufficiency of Municipal Renewable Energy Communities (RECs) in Italy	GIS-based modeling & economic evaluation (NPV, IRR, payback time) of REC scenarios in Rome, Milan, and Palermo. Found higher SSI & better financial returns in Southern Italy due to higher solar radiation	Self-sufficiency in RECs, GIS-based renewable energy planning, scenario-based economic assessment	Scenario-driven analysis of REC feasibility, considering location, PV system size, and investment costs	Municipal Scale (Rome, Milan, Palermo)	Scenario modeling for RECs, integrating GIS-based energy visualization, self-sufficiency metrics (SSI, SCI), and financial indicators (payback time, IRR, NPV) to support policymakers
Dhonju et al. (2022)	Difficulty in sustainable municipal energy planning due to lack of integrated spatial data and decision-support tools	Created an interactive, GIS-based platform allowing users to visualize current energy access, model electrification scenarios (grid, mini-grid, off-grid), and analyze costs spatially	GIS-based energy planning, spatial energy accessibility analysis	GIS-based decision support tool combining spatial accessibility and cost analysis to guide municipal energy planning	Municipal scale (Nepal)	integration of spatial data visualization and cost-based scenario analysis in an interactive GIS platform, applicable to detailed spatial-energy analyses and policymaking in my interface
Urrutia-Azcona et al. (2021)	fragmented decision-making in urban decarbonization planning due to the lack of integrated energy and spatial planning tools	Created a comprehensive interactive dashboard integrating energy consumption, emissions, and potential renewable energy scenarios at urban scale, automated data processing and KPI visualization	Urban decarbonisation planning, GIS and BI integration, CO_2 emission scenarios	GIS and BI integrated dashboard for scenario analysis and KPI visualization to support municipal-level decarbonisation decisions	City-level, Basque region (Spain)	Inspired by their integration of GIS and BI (PowerBI) for interactive scenario visualization, automated KPI generation (energy consumption, emissions), and spatially explicit data analysis, useful for decision-making and policy-oriented visualization

Bianco et al., 2021	Evaluating technical and environmental performance in energy communities using KPIs	Introduced KPIs to technically and environmentally assess and compare energy communities	Key Performance Indicators (KPIs), self-production indexes, emission reduction, scenario evaluation	Use of clear, standardized KPIs (SPI, SCI, renewable penetration, emissions) to quantitatively assess and compare renewable energy scenarios	Campus and District level, Savona, Italy	Integration of clearly defined KPI frameworks into an interface, enabling policymakers to intuitively visualize and compare scenario outcomes
NREL & USAID (2019)	Need for reliable, robust, and validated geospatial data and analysis tools for renewable energy planning	Created an interactive platform combining geospatial renewable energy resource data (solar, wind, biomass) with complementary layers (land-use, transmission lines, population density)	Renewable energy potential mapping, GIS-based data visualization, scenario analysis (technical & economic potential)	GIS-based renewable energy scenario analysis integrating comprehensive geospatial data (renewable resources, land-use, infrastructure)	global Scale	interactive GIS visualization of renewable potential scenarios, integration of complementary data layers (land-use, infrastructure), and user-driven geospatial analysis for policy-oriented decision making
Oyarzún-Aravena et al. (2025)	Lack of integrated geographic and infrastructural analysis for renewable energy transition in Chile	Identified optimal renewable energy locations using GIS-based multi-criteria analysis; highlighted critical infrastructural gaps; developed intuitive 2D/3D spatial visualizations	GIS-based renewable energy resource mapping; infrastructure constraints	GIS-based spatial suitability analysis and scenario visualization to inform renewable energy infrastructure and policy decisions	National scale (Chile)	detailed GIS-based spatial suitability analyses, intuitive 2D/3D renewable energy scenario visualizations, and integrated approach combining geographic and infrastructural constraints for clear, actionable policy guidance

Chen & Chen (2021)	Lack of systematic guidelines for effective data visualization in smart grids and low-carbon energy systems.	Provided structured guidelines and categorized visualization methods (GIS maps, animations, AR/VR)	Integration of temporal-spatial visualization, hierarchical interface structure (primary, secondary, auxiliary layers), and user-friendly design principles	hierarchical visualization methods tailored to different user needs, including policymakers, enhancing readability & interaction with energy data.	Multi-scale (Building, Urban, Regional, Global context)	hierarchical structuring of spatial-temporal energy data into clearly defined interface layers (primary, secondary, auxiliary), effective integration of GIS mapping with temporal dynamics, and clear guidelines enhancing user interaction
Lea et al. (2017)	Difficulty in visualizing costs, efficiency, and sustainability aspects of renewable energy (biofuel) production processes	Built and validated intuitive dashboards and scorecards translating complex biofuel data into clear visualizations (cost, efficiency, environmental benefits)	Dashboard visualization, Balanced Scorecard for KPI monitoring	Dashboard and Balanced Scorecard tools effectively translating complex renewable energy production data into intuitive visual KPI-driven financial and environmental indicators	Micro-scale biofuel production, Industrial context (Kaohsiung, Taiwan)	intuitive KPI dashboard visualization and balanced scorecard approach clearly translating complex renewable energy processes, costs, and sustainability into accessible visual insights for policymakers

Wilson (2016)	Inadequacy of traditional visualization methods (pie charts, bar charts, Sankey diagrams) to represent variability and seasonality in low-carbon energy systems	Successfully demonstrated SAED, offering clearer visualization of energy system variability compared to traditional methods, enhancing stakeholder understanding	Visualization of renewable variability; multi-vector energy (electricity, gas, transport fuels); temporal analysis (hourly, daily, monthly, seasonal)	"Shared Axes" diagram integrating multiple energy sources clearly across unified temporal scales (daily, monthly, seasonal)	National scale (Great Britain)	clear integration and visualization of multiple renewable and consumption energy data on shared temporal axes, facilitating intuitive understanding of seasonal and daily variability for policymakers
Rodrigues et al. (2017)	Difficulty in clearly and simultaneously visualizing spatial and temporal energy production data for broad audiences	Developed interactive web platform effectively linking spatial map views with ThemeRiver diagrams, successfully illustrating spatial-temporal dynamics of energy production for power plants	Web-based interactive map and temporal visualization; ThemeRiver for clear representation of power plants' energy production (hourly, daily, monthly data)	wo-tier visualization (spatial maps & temporal ThemeRiver charts)	National scale (Germany)	effective two-tier visualization approach: spatial maps linked interactively with detailed temporal ThemeRiver diagrams clearly showing hourly, daily, monthly variations of renewable energy data, suitable for policy-making purposes

Table 1: Best Practices in Energy Planning Platforms and Studies

2.7 Stakeholder Analysis in Renewable Energy Projects

To ensure the effectiveness of energy data visualization tools, it is essential to align their design with the specific needs and expectations of stakeholders. Numerous studies highlight the importance of tailoring indicators, whether energy, financial, social, or environmental, to the priorities of different actors. This approach enables more targeted, efficient, and transparent planning, monitoring, and decision-making in the context of energy transitions.

The literature identifies a wide range of stakeholders, including Local Policymakers and Public Administrations(Moretti & Stamponi, 2023), Municipal Authorities (Local Governments) (Mutani et al., 2021), Citizens (Prosumers and Consumers) (Ahmed et al., 2024), Investors (Banks, Financial Institutions, Landlords) (Ahmed et al., 2024), Distribution System Operators (DSO, Enexis) (Reijnders et al., 2020), Energy Communities (as Reporting Entities) (Koltunov & Bisello, 2024), and REC Managers / Energy Community Operators (Giannuzzo et al., 2024), among others.

To enhance clarity, the following definitions of the key stakeholder groups involved in Renewable Energy Communities (RECs) are provided:

- **Local Policymakers and Public Administrations**:
  Entities responsible for promoting and facilitating the creation of RECs within their jurisdictions. They play a key role in stakeholder engagement, planning support, regulatory adaptation, and advancing strategic goals such as carbon neutrality targets (Moretti & Stamponi, 2023).
- **Municipal Authorities (Local Governments)**:
  Local governmental bodies that integrate renewable energy projects into public infrastructures and services, promote citizen participation, and ensure regulatory compliance for REC formation (Mutani et al., 2021).
- **Citizens**:
  Individuals or households who participate in RECs either by actively producing and consuming renewable energy (prosumers) or solely consuming it. Their involvement promotes local energy resilience, cost savings, and democratization of energy systems (Ahmed et al., 2024).
- **Financial Stakeholders (Banks, Financial Institutions, Investors)**:
  Financial stakeholders in Renewable Energy Communities (RECs) include a diverse group of actors such as commercial banks, investment funds, institutional investors, energy utilities, public financial institutions, ESCOs (Energy Service Companies), and in some models, citizens acting as micro-investors. These actors provide capital, assess financial viability, and influence the scalability of RECs through funding mechanisms, risk analysis, and return expectations
- **REC Managers / Energy Community Operators**:
  Individuals or entities responsible for the technical and administrative management of RECs, including optimizing system performance, managing user participation, and reporting results to members and institutions (Giannuzzo et al., 2024).

- **Energy Communities (as Reporting Entities)**:
  Legal entities that manage renewable energy projects collectively and report their environmental, economic, and social outcomes to stakeholders and financiers, demonstrating their trustworthiness and value creation (Koltunov & Bisello, 2024).
- **Distribution System Operators (DSOs)**:
  DSOs play a crucial role in keeping the electricity grid running perfectly, especially as more renewable sources come online. inside the framework of Renewable Energy Communities , their job becomes even more complex. They're responsible for making sure local transformers are not overloaded, adapting the grid to accommodate energy coming from a growing number of small, decentralized and autonomous producers, like rooftop solar panels and maintaining overall system stability as supply and demand fluctuate constantly (Reijnders et al., 2020).
- **Energy Policy Organizations and institutions**:
  These organizations take on the important task of ensuring the energy transition leaves no one behind. They make and approve policies, tools, and support systems aimed at helping vulnerable groups, such as low-income households or marginalized communities, having access to Renewable Energy Communities. Beyond above just technical goals, their work focuses on the social side of sustainability—making sure that clean energy initiatives are inclusive, equitable, and responsive to the needs of those most at risk of being overlooked (Ceglia et al., 2022).

When it comes to understanding how Renewable Energy Communities are performing, some indicators become important, particularly the Self-Sufficiency Index and the Self-Consumption Index. Scholars like Mutani et al. (2021) and Giannuzzo et al. (2024) have highlighted these indicators as essential tools for gauging not only how much energy a community can produce and use on its own, but also what that means in real-world terms: saving on energy bills, planning smarter local infrastructure, and reducing carbon emissions.

But these indicators don't stand alone. They connect directly to the priorities and concerns of different groups involved and engaged in the energy transition, from local governments, municipalities, to and utilities, and citizens. To make sense of these relationships, the table below brings together insights from the literature and matches each stakeholder group with the indicators that could be more important for them, Such as financial returns, social equity, environmental impact. This mapping gives us a clearer picture of who needs what and why.

Author(s)	Stakeholder(s) involved	Stakeholder Needs & Expectations	Energy indicators	Financial Indicators	Social Indicators	Environmental Indicators
Moretti & Stamponi (2023, Assisi)	Local Policymakers and Public Administrations	Use RECs to meet climate goals (e.g. Assisi SECAP -40% CO_2 by 2030), offset emissions in historic centers, facilitate PV installation	Energy production, Self-sufficiency index, Oil equivalent saved (Tons)	—	—	Tons CO_2 avoided
Moretti & Stamponi (2023, Assisi)	Local Policymakers and Public Administrations	Engage stakeholders (citizens, SMEs, religious institutions), combat energy poverty, increase public building participation.	—	CAPEX, OPEX, Payback Time, NPV, IRR, Revenue from incentives/self-consumption	Number of buildings/citizens involved, User types	—
(Ahmed et al., 2024)	Local Governments / Municipal Authorities	Addressing energy poverty, Provide regulatory and infrastructural support	Number of active RECs in their jurisdiction, Installed capacity (kW)	—	—	GHG emissions reductions
Mutani et al. (2021)	Municipal Authorities (Local Governments)	Guarantee continuity of public services (especially municipal lighting), improve energy security, Comply with regional regulations for EC establishment	Total Consumption (TC), Total Production (TP), Self-Consumption (SC), SSI, SCI	—	—	Exposure factor (e)

Giannuzzo et al. (2024)	Policymakers and Public Authorities	Evaluate policy effectiveness in promoting RECs, Monitor energy transition progress at regional/national level, Understand social and environmental impact of RECs	Self-Sufficiency Index (SSI), Total Installed Power, Energy Community Growth	—	—	CO_2 Emissions Avoided
De Franco et al. (2023)	Municipal Government / Public Administrators	Promoting and supporting ECs (especially in infrastructure-poor neighborhoods), Provide reliable and comprehensible energy info to citizens, Lead initial investment in infrastructure for REC creation	—	—	—	—
Ceglia et al. (2022)	Energy Policy Organizations	Tools and methods for integrating vulnerable populations in RECs, Assessing social sustainability of energy interventions	—	Low absolute energy expenditure, High energy expenditure share	Low Income High Costs (LIHC), ISEE-based assessments	—
(Ahmed et al., 2024)	Citizens (Prosumers and Consumers)	Lower energy bills (cost savings through participation in an REC), Self-sufficiency and resilience, Participation in local decision-making	Energy generated vs consumed, Energy shared within community	Income from selling excess energy	—	—

Mutani et al. (2021)	Residential Users: Consumers and Prosumers	Reduce energy bills, Benefit from economic incentives (e.g., self-consumption savings), Improve reliability and reduce blackout risk,	Annual Energy Consumption, PV production, Self-Consumption (SC)	—	—	—
Reijnders et al. (2020)	Citizens	Access real-time information about energy consumption and production, energy cost savings and more efficient consumption	PV production, Energy consumption over time (daily/weekly trends)	Pricing forecast for 24 hours	—	—
Giannuzzo et al. (2024)	REC Members (Citizens, Businesses)	Reduce energy costs, Understand financial and environmental benefits of participation, Gauge self-consumption and energy independence	Self-Consumption Index (SCI), Share of Renewable Energy Consumed	Energy Bill Savings	—	CO_2 Emissions Avoided
De Franco et al. (2023)	Citizens	Autonomy in energy decisions, Participation in community-level decision-making, Economic savings on energy, Better access to local energy consumption and production data,	Individual and neighborhood energy use	Opportunities for local energy savings, Data presented before energy bills	—	CO_2 saved depending on technology
(Ahmed et al., 2024)	Financial Stakeholders (Banks, Financial Institutions, Investors)	Economic feasibility and returns, predict system behavior, forecasting	—	Total investment required and ROI, Cost-benefit	—	—

		and strategic evaluation to support funding decisions and risk analysis		from collective ESS (Energy Storage System)		
Giannuzzo et al. (2024)	Financial Stakeholders (Banks, Financial Institutions, Investors)	Assess return on investment and economic viability of REC projects, Identify key cost-benefit tradeoffs, Support decision-making for funding or loans	—	PBT,NPV, Internal Rate of Return (IRR), CAPEX & OPEX	—	—
Mutani et al. (2021)	Energy Community as a Collective Entity	Maximize internal energy exchange to reduce dependency on the grid, Fulfill minimum regulatory thresholds, Optimize collective performance for eligibility to incentives	Collective Self-Consumption (CSC), Still Uncovered Demand (SUD), Still Over Production (SOP)	Cost-benefit analysis (Global Cost CG, Annual Energy Cost CE)	—	—
Reijnders et al. (2020)	Energy Community (GridFlex Heeten Initiative)	Maximize local self-consumption, Benefit from lower dynamic grid tariffs, optimizing shared behavior	Total energy usage across 23 households, consumption at each demand level (pre/post battery installation), Peak demand occurrence	—	—	—
Giannuzzo et al. (2024)	REC Members (Citizens, Businesses)	Reduce energy costs, Understand financial and e i nvironmental benefits of participation, Gauge	SCI, Share of Renewable Energy Consumed	Energy Bill Savings	—	CO_2 Emissions Avoided

		self-consumption and energy independence					
(Koltunov & Bisello, 2024)	Energy Communities (as Reporting Entities)	prove they are trustworthy, green, and better than traditional utilities, to attract funding from banks or SMEs and private investors, show they create value for society especially new or older ECs	—	Economic outcomes (No specific indicator mentioned)	Social impact (No specific indicator mentioned)	Environmental impact (No specific indicator mentioned)	
(Ahmed et al., 2024)	Energy System Operators (DSOs, Utility Companies)	Balance between grid and local energy generation, Real-time energy flow monitoring	Grid imports/exports from RECs, Observability gaps in low-infrastructure areas	—	—	—	
Reijnders et al. (2020)	Distribution System Operator (DSO) – Enexis	Monitor and manage **transformer load**, Test new tariff structures without regulatory constraints, monitor peak shaving as it postpones the need for expensive network upgrades,	Peak transformer load (measured in kW) with and without community action, Percentage reduction in high-demand periods (e.g., 36% reduction with storage), Network Losses ((Energy Input to Grid−Energy Delivered to End Users) / Energy Input to Grid−Energy)	—	—	—	

Giannuzzo et al. (2024)	REC Managers / Energy Community Operators	Track REC performance and efficiency, Report to members and institutions, Optimize technical operations and user participation	Energy Losses, Energy Not Shared, Energy Autarky, Balance of Consumption vs. Production	—	Participation Rate	—

Table 2: Stakeholders and their core interest Renewable Energy Communities

This stakeholder-indicator mapping highlights the diversity and specificity of stakeholder needs in the context of renewable energy communities. By identifying the most relevant indicators across energy, financial, social, and environmental domains, this synthesis lays the groundwork for the next chapter, which will detail the methodological framework adopted in this thesis. The forthcoming section will build on these insights to justify indicator selection, outline the tools used, and describe the design and implementation process of the proposed data visualization interface.

Chapter 3: Methodology

This chapter of this thesis is dedicated to show the methodological approach that is being used to identify and visualize the most important and relevant indicators that are crucial for renewable energy communities, with a specific attention on the needs and perspectives of different groups of stakeholders . The process starts with a detailed mapping of stakeholders who are involved in the planning and management of renewable energy communities, followed by a detailed review of academic and policy literature to understand which indicators are most commonly used and for what reason. Then, cross-referencing applied with current national and European policies and documents, in order to ensure coherency. Based on this approach, a selection of indicators has been done, considering both their technical relevance and their usefulness for decision-makers. The final step is dedicated to the way of designing and visual representations tailored to each group of stakeholder, to making complex data more understandable, interpretable and practically useful for planning and engagement.

3.1 Stakeholder Mapping and Interest Identification

The transition that is happening toward renewable energy communities needs involving and engaging a diverse set of stakeholders, each with their specific needs, decision-making objectives and goals, and their expectations.
A systematic review of recent papers which have been done between 2019 to 2025, was conducted to extract the stakeholder priorities and their interests, and then carefully cross-validated through both qualitative and quantitative analysis.
This section is demonstrating the primary needs of each group of stakeholder, with the attention focusing on their decision-support requirements across energy, financial, social, and environmental categories.

3.1.1 Local Policymakers and Public Administrations

At the local level, public administrations and elected officials are at the forefront of translating national and European energy policies into tangible action. Their work is grounded in the day-to-day realities of planning, budgeting, and managing public infrastructure, but increasingly, it also involves responding to broader environmental goals—most notably the shift toward climate neutrality by 2050 (Moretti & Stamponi, 2023; Giannuzzo et al., 2024).

For these actors, renewable energy is not just a technical issue but a political and strategic one. Decisions about where and how to invest in solar installations, energy efficiency measures, or district-level energy projects are shaped by the need to balance economic constraints with long-term sustainability. Being able to evaluate whether local energy production can realistically meet consumption demands is essential—not only to avoid overdependence on the national grid, but also to ensure that public funds are directed toward the most impactful interventions.

Beyond technical assessments, there’s a growing awareness that the energy transition cannot succeed without broad-based participation. Policymakers are increasingly expected to create conditions that encourage citizens, small businesses, schools, and public institutions to take part in local energy initiatives. This means designing not only policies, but also tools—like accessible dashboards or planning platforms—that help people understand the energy choices available to them and the collective impact of those choices.

Also, public administrations also carry the responsibility of justifying public investment. Tools that allow for clear comparisons of capital costs, operating expenses, and estimated payback periods are essential in building political and social support for new energy initiatives. As the scope of local energy planning expands, so too does the need for data-driven, yet inclusive, decision-making instruments that can respond to both environmental urgency and local context.

.3.1.2 Municipal Authorities / Local Governments

Municipal authorities play a direct and operational role in implementing Renewable Energy Communities (RECs) and managing local energy systems. Their responsibilities span from maintaining essential public services, such as municipal lighting and energy supply for public buildings — to enabling the conditions for REC establishment through infrastructure planning and regulatory compliance.

In the current energy transition context, their needs are increasingly shaped by the **requirement to reduce local energy vulnerability**, **enhance energy autonomy**, and **support social inclusion** through REC expansion. This includes both **technical priorities**, such as ensuring that public services are supported by reliable and locally sourced renewable energy, and **strategic priorities**, such as allocating municipal resources where energy poverty risks are highest.

Accordingly, they require access to actionable indicators that support **operational planning and investment targeting**. These include:

- **Total municipal energy demand and supply balance** (Total Consumption, Total Production);
- **Self-Consumption Index (SCI)** and **Self-Sufficiency Index (SSI)** to evaluate energy resilience;
- **Exposure Factor (e)** to assess vulnerability in energy supply across districts or services;
- **Number of active RECs** and **Installed Renewable Capacity (kW)** within municipal boundaries to track implementation progress;
- **GHG Emissions Reductions** at the local level to align with broader climate objectives.

This combination of **technical performance** and **equity-based metrics** allows municipal authorities to not only maintain basic energy functions but also play a strategic role in steering inclusive, low-carbon urban energy transitions.

3.1.4 Energy Policy Organizations

Organizations working on energy policy—whether at the national, regional, or nonprofit level—play a crucial role in shaping the ethical and social dimensions of the energy transition. Their work goes beyond promoting renewable technologies or setting carbon reduction targets; it often focuses on ensuring that the shift toward cleaner energy systems is fair, inclusive, and attentive to those most at risk of being left behind.

A central concern for these organizations is the persistence of energy poverty, especially among low-income households that may struggle to pay their bills or access renewable energy options. These groups advocate for policy frameworks and tools that actively address such inequalities, ensuring that vulnerable populations are not excluded from the benefits of Renewable Energy Communities (RECs). For this reason, they often rely on indicators such as the Low-Income High Cost (LIHC) index, the proportion of household income spent on energy, and affordability benchmarks tied to ISEE scores (Ceglia et al., 2022).

What these organizations need from a visualization platform is clarity: a way to track progress on social equity goals, monitor participation rates among marginalized groups, and support policies that make community energy initiatives genuinely inclusive. Their role is as much about shaping narratives and priorities as it is about interpreting data—so the ability to present social metrics in accessible, policy-relevant terms is essential.

3.1.5 Citizens

Citizens are at the main core of every energy transition that is happening across the world, whether as consumers or prosumers, consequently, it is crucial to increase the awareness of their role in shaping more sustainable energy systems. Their motivations can be different: for some of them, it’s about the reduction in energy bills; for some others, it's about how they can contribute to climate action or to gain more independence from traditional and centralized utility providers.

What makes citizens involved in renewable energy communities is basically a blend of practicality and principle. The idea of producing and using one’s own electricity, particularly when it is shared with other neighbors, can make citizens feel empowered. It makes the energy from a passive expense into something active, local, and at the same time meaningful. Lower energy bills, increased self-consumption, and reduced dependency on external energy utilities are tangible results, which make the renewable energy communities model attractive for citizens (Ahmed et al., 2024).

But it should be noted that meaningful participation needs having the access to understandable and transparent data. Most of the people don’t have the time or knowledge to interpret raw data, but they care about clear, well-designed visualizations that have the ability to show their energy usage and money savings. Being able to see how their behavior affects both their wallet and their neighborhood or community, can help build trust, and longer-lasting engagement and involvement (Reijnders et al., 2020).

3.1.6 REC Members (Citizens and Businesses)

Within energy communities, REC members, combining residential participants and local businesses, prioritize **maximizing shared energy use**, **achieving collective financial benefits**, and **demonstrating environmental contributions**.
Their main interests revolve around optimizing **Collective Self-Consumption (CSC)**, reducing overall **energy costs**, and tracking **GHG emissions reductions** associated with community-level renewable energy production (Giannuzzo et al., 2024).

3.1.7 Public and Private Financial Stakeholders (Banks, Funds, Investors)

Financial stakeholders play a pivotal role in enabling the development and scalability of Renewable Energy Communities (RECs). This group includes **commercial banks**, **investment funds**, **institutional investors** (e.g., pension or infrastructure funds), **energy utilities acting as strategic investors**, **public development banks**, **ESCOs (Energy Service Companies)**, and in cooperative models, **citizens acting as micro-investors**. Their engagement is primarily motivated by the financial viability and risk-return profile of REC projects, as well as by alignment with broader environmental, social, and governance (ESG) objectives (Giannuzzo et al., 2024; Ahmed et al., 2024).

These actors require **clear, standardized financial indicators** to evaluate project bankability and manage investment decisions. Key metrics include **Capital Expenditure (CAPEX)**, **Operating Expenditure (OPEX)**, **Net Present Value (NPV)**, **Internal Rate of Return (IRR)**, **Payback Time (PBT)**, and **total projected revenues**, especially those derived from energy self-consumption and grid feed-in incentives. In performance-based financing models, such as those used by ESCOs, **guaranteed energy savings** and **cash flow stability** are essential for investment recovery. For institutional and impact investors, additional attention may be given to indicators capturing **social returns**, such as energy poverty mitigation or inclusive participation.

Moreover, financial stakeholders often operate under stringent risk assessment frameworks. Thus, indicators related to **market stability**, **regulatory predictability**, and **project scalability** influence their long-term engagement. Providing visibility on these metrics is essential for attracting blended financing schemes and ensuring the financial sustainability of RECs over time.

3.1.8 Energy System Operators And utilities

For the energy system operators and utilities, particularly Distribution System Operators, and utility companies, the transition to decentralized energy models introduces both opportunities and new challenges. Their responsibility depends on ensuring the reliability and stability of the grid, even as more households and communities started to produce their own energy demand with solar and other renewable sources.

As local energy production is increasing, these operators must keep a nuanced balance between supply and demand at the neighborhood or at the municipal level. This needs a very detailed understanding of energy dynamics across the network. Indicators like transformer peak loads, net imports or exports from renewable energy communities, and the amount of energy lost when distribution is happening, become essential tools for day-to-day operation and for the planning of infrastructure in the long term period (Reijnders et al., 2020).

3.1.9 REC Managers and Operators

Managers of Renewable Energy Communities (RECs) wear many hats. They are not only responsible for keeping the technical side of the community running smoothly on a day-to-day basis, but also for making sure the community grows in a fair, inclusive, and financially sound way. Their work touches on several key areas, energy flows, budgeting and costs, and community engagement, which means they need a wide range of information to make informed decisions.

From a technical standpoint, managers must keep a close eye on how much energy is being generated, how much is used locally, and whether any losses are occurring along the way. This helps pinpoint inefficiencies and areas where the system could be improved. But technical performance alone doesn’t paint the full picture. It's equally important for them to understand how engaged the members of the community are, whether people are actively participating, sharing energy, and feeling involved in the project’s success (Giannuzzo et al., 2024).

Financially, the goal is to keep the community sustainable. Managers need to know how much it costs to operate, what kind of savings or benefits members are seeing, and whether the financial model will hold up over time. These insights can't come from generic utility statistics, they need to be tailored to the specific characteristics and goals of each REC.

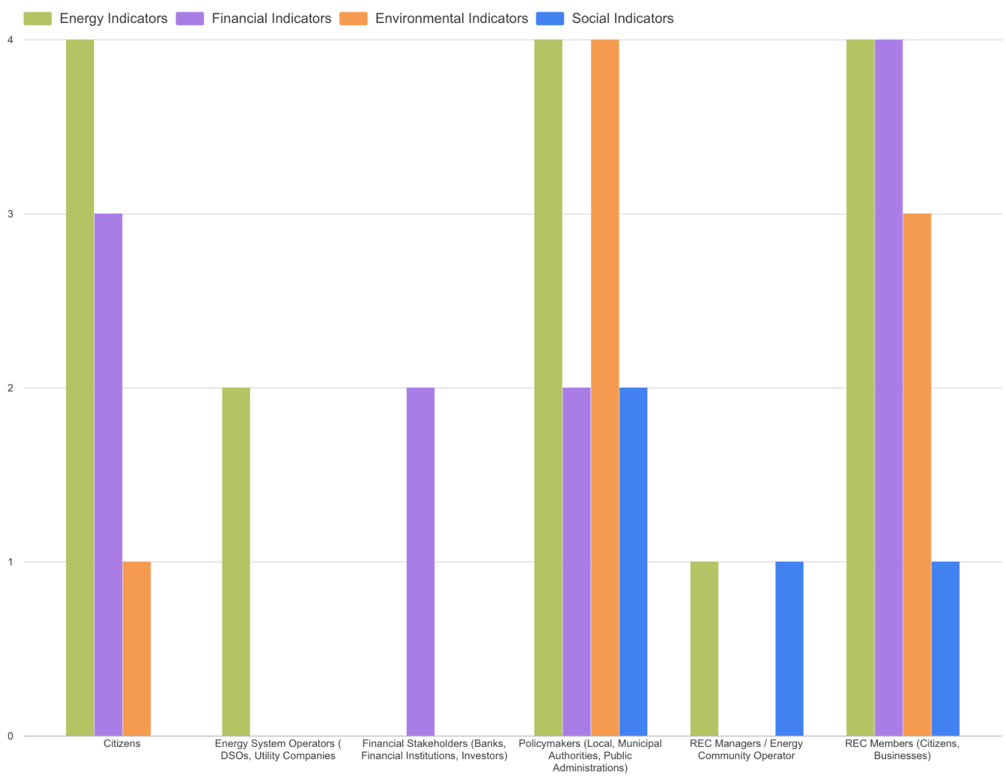

Figure 1: Distribution of energy, financial, social, and environmental indicators across stakeholder groups (indicator count per category)

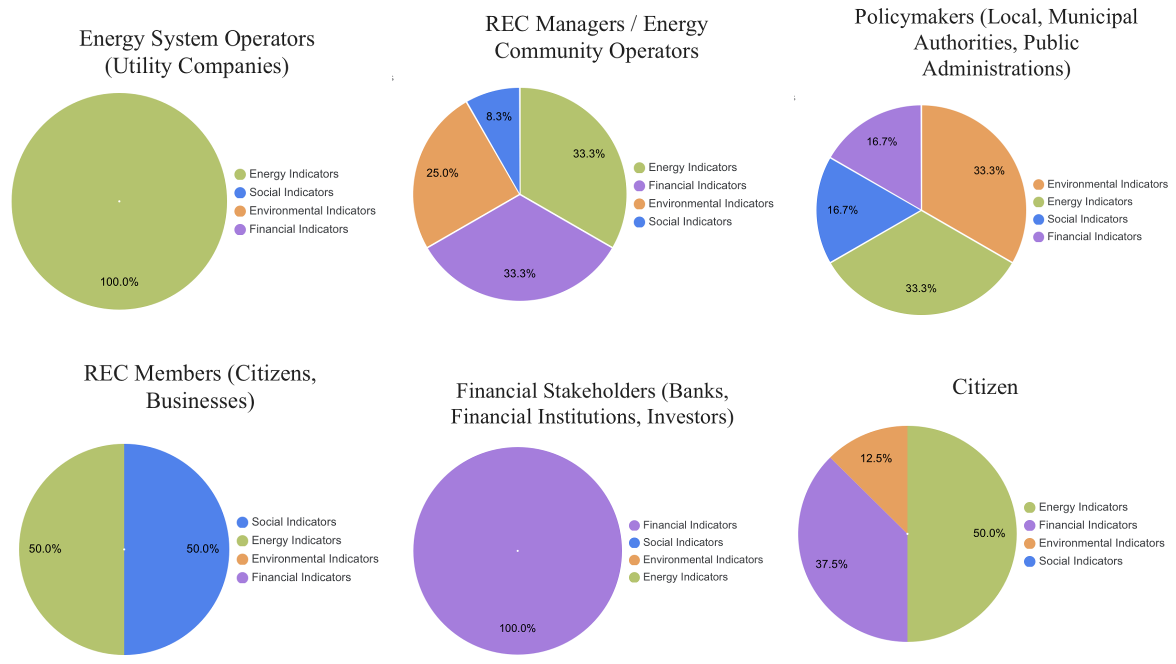

Figure 2 : Internal distribution of indicator types (energy, financial, social, environmental) for each stakeholder group. Each pie chart shows the relative percentage of indicator types based on the stakeholder's mapped needs and priorities.

Indicator	Indicator Mentions in Selected Articles
Energy Consumption Metrics (Daily, Annual, Monthly; Individual and Neighborhood Levels)	9
CO_2 Emissions Reduction	6
Self-Consumption Rate (SC)	6
Photovoltaic (PV) Energy Production	6
Annual Energy Cost Savings (Energy Bill Reduction)	5
Citizen Participation Metrics (Participation Rate, User Types, Number of Buildings, Active Energy Communities)	4
Grid Performance Indicators (Network Losses, Peak Transformer Load, Grid Imports)	4
Internal Rate of Return (IRR) and Return on Investment (ROI)	3
Capital Expenditures (CAPEX) and Operational Expenditures (OPEX)	3
Self-Sufficiency Index (SSI)	3
Net Present Value (NPV)	2
Cost-Benefit Analysis of Collective Energy Storage Systems (ESS)	2
Revenue from Excess Energy Sales	2
Payback Period	2
Low-Income High-Cost (LIHC) Indicator	2
Uncovered Energy Demand (UD)	2
Overproduction Index (OPI)	2
Local Energy Savings	1
High Energy Cost Burden (High Energy Expenditure Share)	1
Exposure Factor (E)	1
Energy Autarky (Energy Independence)	1
Intra-Community Energy Sharing	1
Energy Community Expansion Rate	1
Oil-Equivalent Energy Savings (tons)	1

Table 3: Frequency of specific energy, financial, social, and environmental indicators across the reviewed literature (2019–2025).

3.2 Systematic Literature Review for Indicator Identification

To ensure a scientifically grounded and stakeholder-relevant selection of indicators for the Renewable Energy Community (REC) data visualization platform, a systematic literature review (SLR) was conducted.

Following established definitions in academic literature, a systematic literature review aims

to comprehensively identify, critically appraise, and synthesize all relevant research addressing a specific topic or phenomenon, minimizing bias through transparent and reproducible procedures (ScienceDirect, 2024; Wiley, 2024).
In this thesis, the SLR served to identify key performance indicators (KPIs) relevant to REC projects, focusing on energy, financial, social, and environmental dimensions linked to the specific needs of different stakeholder groups.

The review combined both qualitative synthesis and quantitative analysis, forming the methodological foundation for stakeholder mapping and indicator selection.

3.2.1 Search Strategy and Sources

To make a powerful foundation for this research, a systematic literature search has been done using most important academic databases such as Scopus, Web of Science, and ScienceDirect. to bridge academic findings with real-world applications, the review was complemented by grey literature, particularly reports and technical documents from key institutions and foundations, like the European Commission's Joint Research Centre (JRC) and the International Energy Agency (IEA).

The search was also guided by several carefully selected keywords, used both individually and in combination, such as: "Renewable Energy Communities," "Energy transition indicators," "Stakeholder needs in RECs," "Sustainability indicators," and "Energy community performance metrics." The timeframe is restricted to the publications between 2019 and 2025, allowing the review to have the most recent progress in community energy systems, digital tools, and specially participatory governance models.

This initial point of search has been done around 60 relevant studies, which were selected through a combination of keyword matching for thematic relevance.

3.2.2 Inclusion Criteria

Publications were considered eligible for inclusion if they met the following conditions:

- Focused explicitly on Renewable Energy Communities (RECs) or comparable community-based energy models.
- Addressed stakeholder-specific needs, decision-making priorities, or proposed key performance indicators.
- Were peer-reviewed journal articles, conference papers, or official institutional reports.
- Published in English between 2019 and 2025.

3.2.3 Data Extraction and Synthesis

For each selected study, a structured data extraction process was applied to capture:

- The identified stakeholder groups.
- Their associated needs, priorities, and decision-making expectations.
- Relevant energy, financial, social, and environmental indicators linked to each stakeholder.

To bring together the insights gathered, I compiled a Stakeholder–Needs–Indicator Mapping Table that outlines the main priorities of each stakeholder group alongside the indicators most relevant to their decision-making processes (as detailed in Section 3.2). Alongside this, I ran a frequency analysis to see which indicators appeared most often across the reviewed studies. This helped reinforce which metrics matter most in practice. By combining a qualitative understanding of stakeholder needs with a quantitative look at indicator prevalence, the project lays a solid foundation for designing a platform that is both relevant and responsive to real-world energy planning challenges.

3.3 Indicator Alignment with International Sustainability and Energy Policy Frameworks

This section outlines how the selected energy indicators for the data visualization platform are aligned with major international policy frameworks and organizations, including the International Energy Agency (IEA), United Nations Sustainable Development Goals (SDGs), and the European Commission Joint Research Centre (EU JRC). The goal is to ensure that the platform not only reflects stakeholder needs (as mapped in earlier sections) but also adheres to scientifically validated and policy-relevant metrics, enhancing its credibility, replicability, and relevance for long-term governance.

Methodological Approach

The process of aligning the indicators with broader energy policy and sustainability goals unfolded in three main steps.

First, a comprehensive pool of indicators was gathered, by drawing from the stakeholder-indicator mapping outlined in Section 3.2, the frequency analysis in Section 3.3, and by considering their actual relevance to performance tracking in renewable energy communities.

Next, some key policy frameworks were reviewed to serve as references. This included several publications from the International Energy Agency, such as CO_2 Emissions in 2023, Energy Efficiency 2023, and Renewables 2023, United Nations' Sustainable Development Goals Report 2023, and a series of technical reports from the European Commission's Joint

Research Centre (JRC), particularly those addressing KPIs for RECs, implementation strategies, and the Level(s) framework for sustainable buildings.

Indicators mentioned in the documents

1. CO_2 Emissions that is Avoided

- **IEA : CO_2 Emissions in 2023**:
  "Avoiding emissions through clean energy deployment was critical for limiting the CO_2 increase." (p. 4)
  Quantifies CO_2 avoided from solar, wind, heat pumps, etc. Estimated savings of 550 Mt since 2019.
  → Directly supports inclusion of **"CO_2 Emissions Avoided"** as a REC performance metric.
- **SDG 13.2 – Integrate climate change into national policies**
  → REC contribution to CO_2 mitigation aligns with global targets for climate neutralityJSE_03.04_04 (1).
- **JRC136475_01**: Lists **"GHG emissions avoided"** and **"% GHG reductions"** as standard environmental KPIs for RECsJSE_03.04_04 (1).

2. Self-Sufficiency Index (SSI)

- **JRC136475_01**:
  "SSI measures the percentage of energy demand covered by local renewable production. It reflects community resilience and independence"JSE_03.04_04 (1).
  → The use of SSI as a decision-making and scenario comparison indicator is central in all scenarios (0, 1.1, 4).
- **IEA – Renewables 2023** indirectly supports this through focus on increasing local share of energy mix.
- **SDG 7.2 – Increase substantially the share of renewable energy**
  → SSI expresses progress toward this target at the community levelJSE_03.04_04 (1).

3. Self-Consumption Index (SCI) & Collective Self-Consumption (CSC)

- **JRC136475_01**:
  "SCI = Self-consumed electricity / Total production"; CSC defines energy shared within the community.
  → Key technical KPIs for RECs.
- **EU RED II and RED III Directives** promote **shared self-consumption** as a legal and financial category, tying CSC to incentives and grid supportJSE_03.04_04 (1).

4. Payback Time (PBT), CAPEX, OPEX

- **JRC109286 – Level(s)**: Lists **PBT**, **CAPEX**, and **energy cost per unit** as recommended economic performance indicators.
- **IEA – Energy Efficiency 2023**:
  "PBT is crucial to assess household and community-level returns on energy efficiency investments"
  → Especially relevant in designing incentive programsEnergyEfficiency2023.

5. Energy Poverty Indicators (LIHC, % Households in Energy Poverty)

- **SDG 7.1 – Ensure universal access to affordable, reliable energy**
  - Directly linked to indicators like **Low Income High Costs (LIHC)** and **% of population unable to heat home**.
- **IEA – Energy Efficiency 2023**:
  "Europe saw an increase in people being unable to keep their home adequately warm from 6.9% (2021) to 9.3% (2022)"
  → Validates use of **energy poverty** metrics in evaluating REC equity performanceEnergyEfficiency2023.
- **JRC136475_01**: Includes **"% vulnerable users"** and **"% energy-poor households"** under social indicatorsJSE_03.04_04 (1).

6. Participation Rate

- **JRC136475_01**:
  "Participation rate = Number of active REC users / Total eligible users"
  → Included as an official KPI under **social engagement**, used in EU dashboards for REC monitoringJSE_03.04_04 (1).
- **SDG 11.3 – Enhance inclusive and sustainable urbanization**
  → Community engagement indicators like **participation rate** directly contribute to inclusive energy transitionsJSE_03.04_04 (1).

Indicator Alignment Summary Table

Indicator	Aligned Framework(s)	Policy Support
CO_2 Avoided	SDG 13.2, IEA, JRC	Climate mitigation goals, REC climate impact tracking
Self-Sufficiency Index	SDG 7.2, JRC, IEA	Local renewable autonomy, REC resilience indicator
Self-Consumption Index	RED II, JRC	Prosumption effectiveness, REC operational optimization
Collective Self-Consumption	RED III, JRC	Energy sharing compliance and incentive structure
Payback Time	IEA, JRC Level(s)	Economic viability indicator for both citizens and investors
CAPEX, OPEX	JRC Level(s), IEA	Financial planning, project feasibility metrics
Energy Poverty Index	SDG 7.1, IEA, JRC	Equity and access tracking, policy targeting for vulnerable users
Participation Rate	SDG 11.3, JRC	Community involvement and inclusive governance metrics

Table 4: indicator coherency with international frameworks

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3.4 Final Indicator Selection Process

Overview and Purpose

The goal of this step is to select a final set of indicators that will be integrated into the data visualization interface. This selection ensures each indicator is:

1. Scientifically Valid
– Extracted through literature review, stakeholder mapping, and policy alignment
– Refined through coherence with international standards (IEA, SDGs, EU JRC)

2. Stakeholder-Centered
– Each indicator must clearly address **a specific need or expectation of one or more stakeholder groups**
– Indicators are grouped and selected based on stakeholder relevance, not just general popularity

3. Understandable and Actionable
– Indicators are translated into clear, meaningful phrases that users can easily interpret
– Outputs are expressed using real-world units (e.g., €/year, %, tons CO_2)

4. Contextualized for Platform Use
– Indicators are prepared for dashboard display with appropriate scale (local, regional) and temporal scope (annual, monthly)
– Each metric is selected not only for technical feasibility, but for how well it supports real decision-making

3.4.1 Starting Point: Indicator Pool

The process of selecting the final indicators started with a carefully validated pool of indicators, that is built from three main sources that complemented each other.

First, I looked closely at what the stakeholder groups actual needs. Through the mapping of their concerns and priorities of nine distinct groups, from policymakers and citizens to utility operators, it was possible to identify which indicators are the most important ones.

Then, a systematic literature review has been done and found out how often specific indicators appeared in various renewable energy communities related studies. This helped highlight which metrics are widely used and already tested in real-world contexts.

Then, the comparison has been done with the candidate indicators with major international policy frameworks, such as the Sustainable Development Goals, recent reports from the International Energy Agency, and also the technical guidelines from the European Commission's Joint Research Centre. This ensured that indicators not only made sense just in theory, but also aligned with current policy documents.

3.4.2 Selection Criteria

The final group of indicators included in the data visualization interfaces was selected through a process, which is based on both scientific terms and practical implementation considerations.

The following selection criteria were developed based on a combination of insights from the **systematic literature review**, **stakeholder–needs–indicator mapping**, and **practical requirements of the data visualization platform**. Rather than adopting a single standardized framework, these criteria reflect an interpretive synthesis of academic sources, policy documents (e.g., JRC, IEA, SDGs), and technical constraints related to data availability, user communication, and tool compatibility. While not exhaustive or universal, they offer a transparent and replicable basis for filtering and prioritizing indicators that are both stakeholder-relevant and operationally feasible.

The table below outlines the six criteria applied during the indicator selection process:

Criterion	Definition	Role in Indicator Selection
Stakeholder Relevance	Measures how well the indicator responds to the needs, goals, and expectations of identified stakeholders.	Used as a primary filter to ensure relevance to actual users of the platform.
Data Availability	Refers to whether the indicator can be calculated or approximated using existing ENEA or public data.	Indicators lacking sufficient data were excluded or downgraded.
Policy Alignment	Captures whether the indicator is supported in official frameworks (e.g., SDGs, IEA, EU JRC).	Provided evidence-based justification for inclusion or prioritization.
Technical Feasibility	Assesses if the indicator can be operationalized in GIS or BI tools without excessive modeling effort.	Ensured only implementable indicators reached the dashboard phase.
Interpretability	Evaluates how clearly the indicator can be understood by citizens, stakeholders, or non-technical users.	Required for inclusive and citizen-facing metrics.

Table 5: List of Criteria Used for Indicator Selection

3.4.3 Weighting and Prioritization

Following the selection criteria outlined in Section 3.5.2, a structured and stakeholder-centered **qualitative prioritization** was conducted. Each indicator identified through the literature review and stakeholder mapping was evaluated against five criteria:

- **Stakeholder Relevance**
- **Data Availability**
- **Policy Alignment**
- **Technical Feasibility**
- **Interpretability**

Rather than assigning numerical weights through formal multi-criteria models (such as AHP), this research adopted a **qualitative scoring approach**, based on interpretive synthesis, stakeholder analysis, and practical implementation constraints. Indicators were scored on a **1–5 scale** for each criterion, and classified into one of two levels of priority:

- 🟢 **Top Priority**: Strong relevance, well-supported by data, aligned with policy, technically feasible, and easy to interpret.
- 🟠 **Conditional Priority**: Valuable in specific contexts, but limited by data, technical constraints, or interpretability.

Recognizing the functional diversity of users involved in Renewable Energy Communities, the prioritization process was **customized for each stakeholder group**. The final set of stakeholders was consolidated into four distinct groups to balance clarity with representational completeness:

- **Public Sector & Policy Bodies**: Local and regional governments, municipal departments, national agencies, and planning authorities.
- **Citizens**: Citizens (prosumers and observers), REC members, SMEs participating in or impacted by RECs.
- **Energy DSOs and Utility Operators**: Distribution System Operators, grid managers, and infrastructure planners.
- **Private Companies and Investors**: Banks, investment funds, ESCOs, cooperative finance institutions, REC managers and technical coordinators.

Public Sector & Policy Bodies

Indicator	Relevance	Data Availability	Policy Alignment	Technical Feasibility	Interpretability	Priority Level
CO_2 Emissions Reduction	5	5	5	5	4	🟢 Top Priority
Energy Self-Sufficiency (SSI)	5	5	5	5	4	🟢 Top Priority
Installed Renewable Capacity (kW)	5	4	4	5	4	🟢 Top Priority
Number of Active RECs	5	5	4	5	5	🟢 Top Priority
Self-Consumption Index (SCI)	5	5	5	4	4	🟢 Top Priority
Energy Poverty (LIHC Index)	5	3	5	4	3	🟠 Secondary Priority
Citizen Participation Rate	4	3	5	5	5	🟠 Secondary Priority
CAPEX and OPEX	4	4	4	4	3	🟠 Secondary Priority
Annual Energy Consumption	4	5	3	5	5	🟠 Secondary Priority

Table 6: Indicators Prioritization for Policy Bodies

Citizens

Indicator	Relevance	Data Availability	Policy Alignment	Technical Feasibility	Interpretability	Priority Level
Energy Bill Savings	5	5	4	5	5	🟢 **Top Priority**
Self-Consumption Rate (SCI)	5	5	5	5	4	🟢 **Top Priority**
Payback Time	5	4	5	5	5	🟢 **Top Priority**
CO_2 Emissions Avoided	4	5	5	5	4	🟢 **Top Priority**
Collective Self-Consumption (CSC)	4	5	4	4	4	🟢 **Top Priority**
Real-time Consumption	4	4	3	4	4	🟠 **Secondary Priority**
Renewable Energy Share (%)	5	4	4	4	5	🟠 **Secondary Priority**
Citizen Participation Metrics	4	3	4	4	4	🟠 **Secondary Priority**

Table 7: Indicators Prioritization for Citizens

Energy Distribution System Operators & Utilities

Indicator	Relevance	Data Availability	Policy Alignment	Technical Feasibility	Interpretability	Priority Level

Grid Import/Export Balance	5	5	4	5	5	🟢 **Top Priority**
Peak Transformer Load	5	5	5	5	4	🟢 **Top Priority**
real-time energy generation and consumption	4	5	5	5	4	🟢 **Top Priority**
Self-Consumption Index (SCI)	4	3	4	4	4	🟢 **Top Priority**
Installed Renewable Capacity (kW)	4	3	4	4	4	🟢 **Top Priority**
Overproduction Index (OPI)	4	3	4	4	4	🟠 **Secondary Priority**
Energy Losses - Energy Not Shared	5	4	5	5	5	🟠 **Secondary Priority**

Table 7: Indicators Prioritization for Utilities and Energy System Operators

Private Companies (Financial Institutions, Investors)

Indicator	Relevance	Data Availability	Policy Alignment	Technical Feasibility	Interpretability	Priority Level
Internal Rate of Return (IRR)	5	4	4	5	5	🟢 **Top Priority**
Net Present Value (NPV)	5	4	5	5	4	🟢 **Top Priority**
Payback Time (PBT)	5	5	5	5	5	🟢 **Top Priority**
CAPEX and OPEX	4	5	5	5	4	🟢 **Top Priority**
Revenue from Excess Energy Sales	4	4	3	4	4	🟠 **Secondary Priority**
Total Investment and ROI	5	4	5	5	5	🟢 **Top Priority**

Table 8: Indicators Prioritization for Utilities and Private Companies (Financial Stakeholders)

3.5 Visualization and Indicator Translation Strategy

To make sure that the indicators included in the platform are not just technically sound but also genuinely useful to the people using them, this section explores how each metric has been carefully adapted for clarity and relevance. Rather than presenting terms like "Self-Consumption Index" or "CO_2 Avoided" in their raw technical form, they've been reworded in plain, everyday language. Wherever possible, I've added relatable examples or analogies—such as comparing saved emissions to car trips avoided—to make the information feel more tangible.

Visual choices were equally important. Each metric is paired with a display format that suits the target audience, whether that's a simplified bar chart for citizens or a more detailed comparison dashboard for policymakers. Labels are kept short and intuitive, and tooltips or brief descriptions offer additional context without overwhelming the user.

The goal here is simple: to help users not only understand the data but also act on it. By translating complex concepts into visuals and language that feel familiar, the interface supports smarter decisions—whether someone is managing a local energy community or simply checking how their household fits into a broader sustainability effort.

Public Sector & Policy Bodies

Indicator	Label	Description	Visualization Type

CO_2 Emissions Reduction	**CO_2 Saved Through Clean Energy**	**How much CO_2 has been avoided in your area thanks to local renewable production**	**KPI Card (tons CO_2/year) + line chart (historical trend) + optional map layer (CO_2 savings by area)**
Self-Sufficiency Index (SSI)	**% of Local Demand Met by Renewables**	**What % of your area's total electricity demand is met by local renewable sources.**	**Gauge chart for current SSI (% of local demand met); line chart compares actual vs. solar scenario for 2024.**
Installed Renewable Capacity (kW)	**Installed Renewable Energy (kW)**	**Total renewable energy installed in your area (solar, wind, etc.).**	**KPI card + bar chart by source, with comparison to national/regional benchmark**
Number of Active RECs	**Energy Communities in Action**	**How many energy communities are active in your municipality or region.**	**Dot density map**
Total Consumption & Production	**Energy Demand vs Local Supply**	**How much energy you use vs. how much you produce locally.**	**Dual-line chart** (consumption vs. production), monthly or annual
Self-Consumption Index (SCI)	**Use What You Produce**	**What share of renewable energy is consumed locally.**	**KPI Card**
CAPEX and OPEX	**Investment vs Operating Cost**	**Initial and yearly costs of energy projects.**	**Stacked column chart (CAPEX/OPEX) + doughnut chart**
Energy Poverty (LIHC Index)	**Households at Energy Risk**	**% of vulnerable households facing high energy bills.**	**Choropleth map + ranking table**
Citizen Participation Rate	**% of Residents Engaged in RECs**	**% of citizens participating in RECs.**	**Circular progress bar + mini bar chart comparing municipalities**
Annual Energy Consumption	**Total Electricity Use in the Area**	**Total electricity used in your area last year.**	**breakdown bar by sector**

Overproduction Index (OPI)	**Energy Produced but Not Used Locally (%)**	**% of produced energy exported instead of used locally.**	**bar chart (Produced vs Used vs Exported)** **Corresponding lost revenue (€/year) due to unused energy**

Table 9: Indicator Visualisation Strategy for policymakers

Citizens

Indicator	Label	Description	Visualization Type
Energy Bill Savings	**Your Annual Energy Bill Savings**	**How much money you're saving annually by joining your energy community.**	**Number (€/year) + monthly bar chart**
Self-Consumption Rate (SCI)	**How Much Energy You Use Directly**	**What % of your own solar or shared REC energy you actually consume.**	**Percentage dial (%)**
Payback Time (PBT)	**When Will You Break Even?**	**How many years it takes to recover your investment in renewables.**	**Number (year), mini chart showing average PBT in area**
CO_2 Emissions Avoided	**Your Impact on the Planet**	**How much CO_2 you're helping to avoid by using clean energy.**	**Scorecard (tons CO_2/year) + an icon= 'X trees planted per year'**
Renewable Energy Share (%)	**How Green is Your Energy?**	**What % of your electricity comes from renewable sources.**	**Donut chart + benchmark bar comparing with local/national average**
Citizen Participation Metrics	**How Many in Your Area Joined the REC?**	**Shows how many people in your area have joined a REC.**	**map with member clusters, Dot Map**

Annual Energy Consumption	**Your Yearly Energy Use**	**Total electricity you used over the past year.**	**Line chart (kWh/month)**
Real-time Consumption	**Live View of Your Energy Use**	**See how much electricity you're using right now.**	**Live gauge**
Collective Self-Consumption (CSC)	**How Much Energy the Community Shares**	**What % of REC-produced energy is shared and used within the community.**	**One simple circle showing % shared vs % exported for the selected community**
Energy Poverty (LIHC Index)	**Households Struggling with Bills**	**Share of people in your area with high energy costs and low income.**	**Map overlay with info icon explaining vulnerability**

Table 10: Indicator Visualisation Strategy for Citizens

Distribution System Operators & Utilities

Indicator	Label	Description	Visualization Type
Grid Import/Export Balance	**Energy Flow to and from the Grid**	**How much energy is injected into or drawn from the grid by RECs in your network.**	**Dual-line chart (Import vs Export) over time (hourly/daily)**
Peak Transformer Load	**Transformer Load Peaks**	**Monitors when local transformers reach critical load levels.**	**Load curve with peak flags and alert zones**
Network Losses	**Energy Lost During Delivery**	**% of electricity lost in distribution between generation and end use.**	**KPI Card: Network Loss % (e.g., 3.8%)**
Real-time Generation & Consumption	**Live Power Status in Your Network**	**See current energy generation and usage across your service area.**	**Live dashboard widget with production vs. demand arrows**

Self-Consumption Index (SCI)	**Local Use of Local Power**	**Shows how much locally produced energy is used without grid export.**	**Stacked bar (produced vs. used vs. exported)**
Installed Renewable Capacity (kW)	**Total Installed Renewable Power in Network**	**The total renewable energy potential (kW) across your infrastructure.**	**bar chart by source (solar, wind...)**
Total Consumption & Production	**Overall Energy Flow in Your Area**	**Shows the balance of energy used and produced in your network.**	**Dual-line chart (Production vs Consumption)**
Exposure Factor (e)	**Areas at Grid Risk**	**Highlights locations most vulnerable to outages or infrastructure stress.**	**Risk heat map + infrastructure overlay**
Overproduction Index (OPI)	**Too Much Power, Not Enough Use**	**Measures excess generation that exceeds local demand.**	**Overflow bar with tooltip suggestions**
Annual Energy Consumption	**Total Grid Demand Over the Year**	**Tracks total electricity consumed annually in your area.**	**Line chart (annual trend) + optional comparative bar chart (across zones or years)**

Table 11: Indicator Visualisation Strategy for Utilities and Energy system Operators

Private Companies (Financial Institutions, Investors)

Indicator	Label	Description	Visualization Type

Internal Rate of Return (IRR)	**Annual Profitability Rate**	**Expected % return per year from the REC investment.**	**Single KPI Card showing IRR as a bold percentage (e.g., 12.5%).**
Net Present Value (NPV)	**Today's Value of Future Gains**	**Value today of all future financial returns from the investment.**	**Cumulative Cash Flow Line Chart** **→ X-axis: Years** **→ Y-axis: Cumulative Cash Flow (€)**
Payback Time (PBT)	**When Will This Project Pay Back?**	**How many years until initial investment is fully recovered through savings or revenue.**	**Single KPI Card (e.g., 6.2 Years)**
CAPEX and OPEX	**Setup vs Maintenance Costs**	**Capital investment compared with annual maintenance and operations cost.**	**Stacked bars per project phase**
Revenue from Excess Energy Sales	**Income from Selling Extra Energy**	**Earnings from selling surplus energy back to the grid.**	**Line Chart** **→ Revenue over time (€/month or €/year)**
Total Investment and ROI	**How much the project costs and how much it pays back over time.**	**Combines total required investment with return expectations.**	**Total Investment (€)** **Bar chart (cost vs. return)**
Installed Renewable Capacity (kW)	***Installed Renewable Energy (kW)***	**Total renewable energy installed in your area (solar, wind, etc.).**	**KPI card + bar chart by source, with comparison to national/regional benchmark**
Overproduction Index (OPI)	**Potential Revenue Lost from Exported Energy**	**Unused local energy sold externally, reducing local value retention.**	**Bar chart (Exported % + lost revenue €)**

Table 12: Indicator Visualisation Strategy for Private Companies, Financial stakeholders and Investors

It is crucial to acknowledge the point, that while the methodology was designed to accommodate a comprehensive set of different indicators for various stakeholder groups, the implementation process which will be discussed in the next chapter, encountered certain limitations. Due to constraints in data availability, granularity, and confidentiality and privacy of the collected data by ENEA, particularly regarding financial and economic and grid-specific metrics data, not all proposed indicators and the way to visualize them could be integrated into the functional interface. Nonetheless, the methodological framework remained a guiding structure, ensuring that the final interface design is aligning with the initial stakeholder-driven planning, even if some indicators had to be postponed or simplified.

Chapter 4: Case Study – Development of a Stakeholder-Oriented Energy Visualization Interface

This chapter presents the development of a data visualization interface designed to support energy planning and decision-making within Renewable Energy Communities (RECs). Built upon the methodological foundation laid out in the previous chapters, the interface translates key energy indicators into accessible visual formats tailored to the diverse needs of stakeholders, including local authorities, citizens, utility managers, and financial actors.

The interface serves a **dual purpose**: it functions both as a **decision support tool**, enabling users to compare REC scenarios based on energy performance—and as a **platform for stakeholder engagement**, promoting transparency, participation, and collective understanding of local energy dynamics. The design is grounded in a stakeholder-driven indicator selection process, with metrics such as the Self-Consumption Index (SCI), Self-Sufficiency Index (SSI), and Unused Energy Percentage currently operationalized across three modeled scenarios.

Given the iterative nature of development and pending feedback from academic supervisors, the current version of the interface reflects the indicators and features that are already implemented and validated. Additional indicators (e.g., CAPEX, Payback Time, or Energy Poverty metrics) may be integrated in later stages as data becomes available and stakeholder input evolves. This chapter focuses on documenting the platform's core functionalities, visualization logic, and the role it plays in enabling evidence-based, participatory energy transitions at the municipal level.

4.1 Data Sources and Pre-Processing

The development of the visualization interface required re-structuring the original data produced by ENEA into a format suitable for interactive filtering, scenario comparison, and stakeholder-specific insights. While the dataset already included a rich set of indicators, such as energy consumption, self-consumption, self-sufficiency, overproduction, and uncovered demand, the original format was not immediately compatible with modern dashboard environments like Google Looker Studio.

The data provided was organized in geo-packages within QGIS, with each municipality represented as a row and each indicator as a separate column. Figure 4.1 shows an example of the original structure for Scenario 0, which represents the actual situation without energy sharing. The table includes indicators such as total consumption (C), production (P), self-consumption (SC), overproduction (OP), uncovered demand (UD), Self-Consumption Index (SCI), Self-Sufficiency Index (SSI), and Overproduction Index (OPI).

Unpivoting and Normalization (Python)

Using Python's pandas library, the wide-format tables were unpivoted into a long format. This means that instead of having one row per municipality with all scenario values as columns, the table was transformed to have:

- One row per municipality–scenario–indicator combination.
- A new column named "Scenario" identifies whether the row belongs to Scenario 0 (No Sharing), Scenario 1 (Sectoral Sharing), or Scenario 2 (Residential Sharing).

To organize the data more effectively for visualization, I used Python's pandas library to reshape the tables from a wide format to a long one. Instead of having one row per municipality with several columns representing each scenario and indicator, the table was transformed so that each row now represents a unique combination of municipality, scenario, and indicator. This meant introducing three key columns: one to indicate the scenario (e.g., Scenario 0 for No Sharing, Scenario 1 for Sectoral Sharing, Scenario 2 for Residential Sharing), a second column specifying the indicator (like SCI, SC, or OP), and a third showing the corresponding value.

This restructuring made the data far easier to manage and query, especially when building the dashboard. It also helped maintain clarity—making it possible to compare indicators across scenarios more efficiently—and improved the overall responsiveness of the dashboard interface.

Scenarios 1 and 2 introduced additional indicators that weren't relevant to Scenario 0, such as CSC (Collective Self-Consumption) and a combined value (SC + CSC) reflecting both individual and shared consumption. These extra indicators were handled by tagging them specifically to their respective scenarios, and by linking them to the stakeholders they concern most—like Renewable energy community members or utility providers. This made it easier in order to filter and present relevant data based on user needs.

Once this transformation was complete, I imported the cleaned and structured dataset into Supabase, which uses PostgreSQL. Supabase was chosen because it's fast, flexible, and integrates well with business intelligence tools like Looker Studio. PostgreSQL's ability to handle long-format tables efficiently meant I could write SQL queries that filtered data by municipality, indicator, or scenario without slowing down the system.

I also used SQL views to perform real-time calculations, like percentage shares, conditional comparisons, or grouped sums on the fly. By doing this backend processing in advance, I reduced the workload on the dashboard interface itself. then, the user experience became much smoother: charts loaded faster, filters worked seamlessly, and the data remained consistent and clear across different visual components.

COMUNE	C	P	SC	OP	UD	SCI	SSI	OPI
Agliè	10408630	2507573,36...	2369019,85...	138553,509...	8039610,149...	0,94474597...	0,22760150...	0,05525402...
Airasca	67766540	79212716,98...	52530446,3...	26682270,6...	15236093,6...	0, 663156729...	0,775167897...	0,33684327...
Ala di Stura	1537250,000...	786198,220...	580936,076...	205262,1435...	956313,923...	0,738918076...	0,37790605...	0, 261081923...
Albiano d'Ivrea	3912080,00...	250940,82	250940,82	0	3661139,180...	1	0,064145114...	0
Almese	30318490	3512139,359...	3512139,359...	0	26806350,6...	1	0,115841500...	0
Alpette	706420	20818,86	20818,86	0	685601,14	1	0,02947093...	0
Alpignano	53779370	4879282,56...	4879282,56...	0	48900087,4...	1	0,090727774...	0
Andezeno	17912550	1346057,439...	1346057,439...	0	16566492,5...	1	0, 075146053...	0
Andrate	1010640,000...	67574,36	67574,36	0	943065,640...	1	0,06686293...	0
Angrogna	1613740,000...	8275372,370...	656946,226...	7618426,143...	956793,7731...	0,07938569...	0,40709545...	0,92061430...
Arignano	3694780,00...	362863,370...	362863,370...	0	3331916,630...	1	0,09820973...	0
Avigliana	85242100	14184133,99...	14184133,99...	0	71057966,00...	1	0,16639822...	0
Azeglio	4237690,00...	537385,1499...	537050,095...	335,054284...	3700639,90...	0,99937650...	0,126731803...	0,00062349...
Bairo	3979140,000...	835213,28	800881,090...	34332,18962...	3178258,909...	0,95889410...	0,20126989...	0,041105895...
Balangero	8588280	5983836,81...	3780032,59...	2203804,22...	4808247,40...	0,631707165...	0,44013849...	0,36829283...
Baldissero C...	2997490,00...	181636,7499...	181636,7499...	0	2815853,25...	1	0,06059628...	0
Baldissero To...	7593560,00...	509781,2200...	509781,2200...	0	7083778,780...	1	0,06713336...	0
Balme	417280	4410372,799...	358032,352...	4052340,44...	59247,6479...	0,081179611...	0,85801464...	0,91882038...
Banchette	13123100,00...	32891,12000...	32891,12000...	0	13090208,88	1	0,00250635...	0
Barbania	4272270,00...	329160,889...	329160,889...	0	3943109,110...	1	0,07704590...	0
Bardonecchia	11646480	52346925,5...	5219549,05...	47127376,47...	6426930,94...	0, 099710708...	0, 448165373...	0,90028929...
Barone Cana...	1413500,000...	652883,020...	516778,1086...	136104,91131...	896721,8913...	0, 791532468...	0,365601774...	0, 208467531...
Beinasco	68818050	4185527,039...	4185527,039...	0	64632522,9...	1	0,06082019...	0
Bibiana	10747060	788292,11	788292,11	0	9958767,89	1	0,07334955...	0
Bobbio Pellice	1028400,00...	15174743,82...	411126,2971...	14763617,52...	617273,7028...	0,02709279...	0, 399772751...	0,97290720...

Figure 3: First Version of Data Structure (ENEA's Approach)

comune	c	p	sc	op	ud	sci	ssi	opi	scenario	csc	SC + CSC
Agliè	10408630	2507573.36	2369019.85069206	138553.509307944	8039610.14930794	0.944745979711659	0.227601504779405	0.055254020288341	0	0	0
Airasca	67766540	79212716.9807958	52530446.3496104	26682270.6311854	15236093.6503896	0.66315672977542	0.775167897750283	0.33684327022458	0	0	0
Ala di Stura	1537250	786198.22	580936.076481162	205262.143518838	956313.923518838	0.73891807651404	0.377906050727703	0.26108192348596	0	0	0
Albiano d'Ivrea	3912080	250940.82	250940.82	0	3661139.18	1	0.064145114619333	0	0	0	0
Almese	30318490	3512139.36	3512139.36	0	26806350.64	1	0.115841500021934	0	0	0	0
Alpette	706420	20818.86	20818.86	0	685601.14	1	0.029470937968914	0	0	0	0
Alpignano	53779370	4879282.57	4879282.57	0	48900087.43	1	0.090727774795428	0	0	0	0
Andezeno	17912550	1346057.44	1346057.44	0	16566492.56	1	0.075146053465308	0	0	0	0
Andrate	1010640	67574.36	67574.36	0	943065.64	1	0.066862938336104	0	0	0	0
Angrogna	1613740	8275372.37	656946.226815471	7618426.14318453	956793.773184529	0.079385699814191	0.407095459501203	0.920614300185809	0	0	0
Arignano	3694780	362863.37	362863.37	0	3331916.63	1	0.098209736438976	0	0	0	0
Avigliana	85242100	14184133.995786	14184133.995786	0	71057966.004214	1	0.166398223363643	0	0	0	0
Azeglio	4237690	537385.15	537050.09571545	335.0542845502	3700639.90428455	0.999376509967665	0.126731803344617	0.000623490032336	0	0	0
Bairo	3979140	835213.28	800881.090372588	34332.189627412	3178258.90962741	0.958894104716089	0.201269895096073	0.041105895283911	0	0	0
Balangero	8588280	5983836.82	3780032.59354046	2203804.22645954	4808247.40645954	0.631707165026011	0.440138490307775	0.368292834973989	0	0	0
Baldissero Canavese	2997490	181636.75	181636.75	0	2815853.25	1	0.060596282222793	0	0	0	0
Baldissero Torinese	7593560	509781.22	509781.22	0	7083778.78	1	0.067133363007601	0	0	0	0
Balme	417280	4410372.79963448	358032.352041194	4052340.44759329	59247.6479588059	0.081179611862033	0.858014647337984	0.918820388137968	0	0	0
Banchette	13123100	32891.12	32891.12	0	13090208.88	1	0.002506352919661	0	0	0	0
Barbania	4272270	329160.89	329160.89	0	3943109.11	1	0.077045900657028	0	0	0	0
Bardonecchia	11646480	52346925.53	5219549.05697075	47127376.4730292	6426930.94302925	0.099710708969516	0.448165373312001	0.900289291030484	0	0	0
Barone Canavese	1413500	652883.02	516778.108685993	136104.911314007	896721.891314007	0.79153246884257	0.365601774804381	0.20846753115743	0	0	0
Beinasco	68818050	4185527.04	4185527.04	0	64632522.96	1	0.060820192376855	0	0	0	0
Bibiana	10747060	788292.11	788292.11	0	9958767.89	1	0.073349558856096	0	0	0	0
Bobbio Pellice	1028400	15174743.82	411126.297155657	14763617.5228443	617273.702844343	0.027092799854308	0.399772751026505	0.972907200145692	0	0	0
Bollengo	11237730	607143.94	607143.94	0	10630586.06	1	0.054027275971215	0	0	0	0
Borgaro Torinese	74380530	1296270.49	1296270.49	0	73084259.51	1	0.017427551134685	0	0	0	0
Borgiallo	1202810	123611.42	123611.42	0	1079198.58	1	0.102768866238225	0	0	0	0
Borgofranco d'Ivrea	8815970	1785314.63933926	1785314.63933926	0	7030655.36066074	1	0.202509155468911	0	0	0	0

Figure 4: Data Structure Format After Pre-processing

4.2 Platform Design Philosophy

The platform follows a **user-centered design philosophy**, developed to make energy data not only accessible but also meaningful to the diverse range of stakeholders engaged in Renewable Energy Communities (RECs). The landing page of the platform features a simple, visually distinct **stakeholder selection interface**, where users identify themselves by clicking on one of four options: local/regional authority, Citizens & REC Members, Grid & Utility Managers, and financial stakeholders. Based on their choice, they are redirected to a customized dashboard view with tailored indicators, filters, and visualizations relevant to their role. This design supports targeted communication and enhances the platform's usability for non-technical users. By tailoring the experience to local authorities, citizens, utilities, and investors, the interface promotes both **decision support** and **stakeholder engagement**, in line with the dual goals of this research.

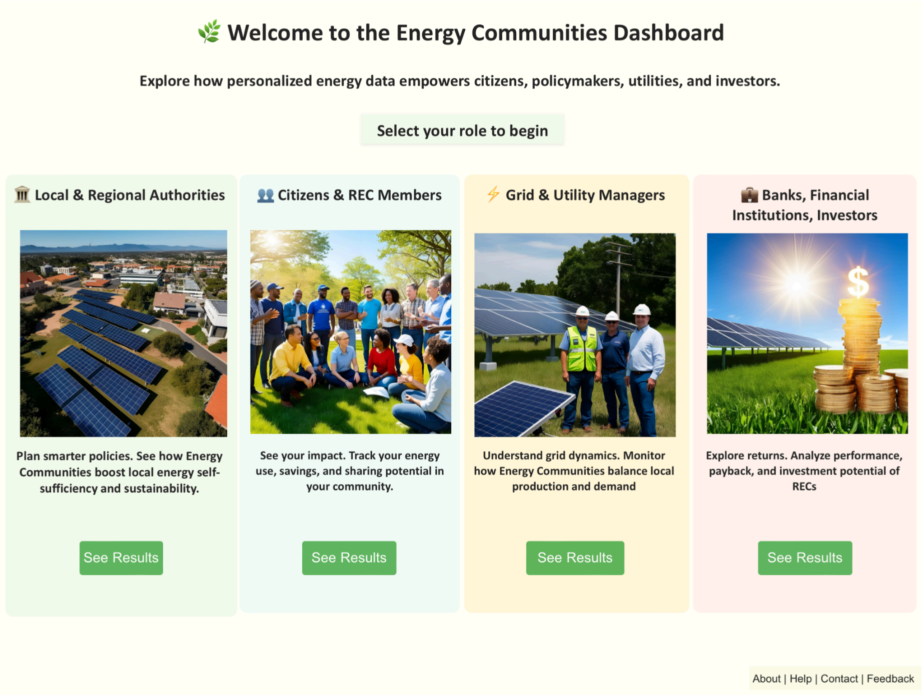

Figure 5: Home Page of the Interface

The architecture integrates several complementary tools:

- **QGIS** served as the starting point, where the original data was organized in geo-packages at the municipal level. Each municipality appeared as a row, with multiple indicators, across different scenarios, as columns. These datasets contained essential information on energy production, consumption, and performance indicators. However, their original wide format was not suitable for real-time, filter-based visualization in a dashboard environment.
- To resolve this, the datasets were transformed using **Python and SQL**, through a process of **unpivoting** the tables into a long, normalized structure. This restructuring enabled more effective filtering by **municipality**, **scenario**, and **indicator type**, and allowed for clearer visual logic in the final interface.
- After reshaping the data, I brought the tables into Supabase, an open-source platform built on top of PostgreSQL. I chose Supabase because it combines the flexibility of SQL with solid performance, especially when handling long-format datasets like mine that have multiple scenarios and municipalities, so it means it has several rows (in some cases, more than 3 million rows). Even with a large volume of data, queries ran rapidly and reliably, which was crucial for maintaining the dashboard being responsive.
- For the front end, **Google Looker Studio** was selected as the primary **Business Intelligence (BI) tool** due to its accessibility, interactivity, and ease of use. Looker Studio allows the creation of dynamic and visually intuitive dashboards that non-technical users can easily navigate. Its **user-friendly interface**, support for **real-time filtering**, and ability to incorporate **simple contextual maps** made it ideal for displaying data at the **municipal scale**. The visual components, such as scenario

cards, KPI indicators, comparative bar charts, and interactive graphs—were designed to adapt based on user selections, enhancing exploration and decision-making.

The layout of the platform reflects the core values of **clarity, accessibility, and role-specific relevance**. Users begin by selecting their role - local/regional authority, REC member, utility operator, or private companies (financial stakeholder, investors) - on the welcome page. Each role directs them to tailored dashboards where filters allow further selection of:

- Municipality
- Scenario (No Sharing, Shared Across Sectors, Shared Within Residential Sector)
- Performance dimension (Energy Overview, Economic Impacts)

4.2.1 Tool Evaluation and Selection

The step for selecting the most appropriate visualization platform for the interface was based on a comparative evaluation of three candidates: Google Looker Studio, Microsoft Power BI, and Esri ArcGIS Experience Builder. The assessment was taking into account key criteria such as ease of use, both for the designing part and for end users, integration with existing data format, responsiveness, flexibility, and how suitable it is, for presenting complex energy data to a range of different stakeholders with different expertise.

Google Looker Studio emerged as the preferred and final choice, due to its intuitive interface, seamless integration with PostgreSQL databases via Supabase,zero licensing costs, and its cloud-based system, which makes it accessible for almost all different operating systems, including macOS, ensuring and garanting its usability for all the uses, regardless of their device or their platform. Its drag-and-drop function makes it possible for efficient dashboard development, while built-in filtering tools and support for basic mapping, using Google Maps, allows for the clear and user-friendly presentation of energy indicators across scenarios and municipalities. Although for sure the platform has some limitations, particularly in terms of advanced data blending and the ability to handle very large datasets, its simplicity and accessibility made it particularly appropriate for non-technical users, such as local authorities, residents and also investors.

On the other hand, Microsoft Power BI offers a more advanced and complex analytics environment, with powerful data modeling features and also supporting real-time data streams, and the ability to implement complex calculations using DAX. However, it is worth mentioning that these advantages are accompanied by a steeper learning curve and a user interface that may be less accessible to stakeholders who are not having enough expertise and unfamiliar with business intelligence tools and its environment. Furthermore, licensing requirements for certain features could pose limitations in projects aiming for open, widely accessible dissemination. Additionally, while a web version of Power BI is is provided for all, it offers limited functionality with respect to its desktop version, which is not supported on some operating systems such as macOS, potentially limiting the access for users on non-Windows systems.

Esri ArcGIS Experience Builder was also one of the candidates, particularly for its strong capabilities in geospatial data visualization and support for responsive, map-centric applications. It is especially effective and strong in projects with a high degree of spatial storytelling or 3D content. But, its interface design requires more customization effort, and it is less optimized for economic and performance indicator visualization when compared to business intelligence platforms such as Google Looker Studio. Furthermore, its reliance on the Esri ecosystem may limit interoperability and accessibility for some users.

By taking into consideration all of these advantages and disadvantages, **Google Looker Studio** offered the most balanced solution. While it is not the most powerful tool in absolute terms, it aligned best with the project's goals and this research objectives: to deliver a clear, interactive, understandable and role-specific interface that supports both decision-making and stakeholder engagement across the Renewable Energy Communities context.

4.3 Scenario Modeling

The platform integrates three energy scenarios adapted from the Italian national geoportal for Renewable Energy Communities (RECs), originally developed by ENEA. While the geoportal study defines six scenarios (Scenarios 0 to 5), this interface focuses on three of them, Scenario 0, Scenario 4, and Scenario 5, which are the most relevant for understanding the direct effect of energy communities on local energy flows.

Simplification and Naming of the scenarios in the interface

To ensure the interface remains accessible and engaging for a big range of users, we intentionally translated the technical scenario names into a more simple names:

- Scenario 0 → "No Sharing"
  This scenario shows the actual situation, in which each user consumes only the energy they produce, without any energy exchange between other users.
- Scenario 1 → "Shared Across All Sectors"
  In this scenario, energy is shared among residential, commercial, and public users, which reflects a more integrated and collaborative community model in energy sharing.
- Scenario 2 → "Shared just Within Residential Sector"
  In this scenario, only residential users share energy among each other. Only 25% of the residents act as prosumers, the rest act as consumers.

This renaming strategy, visible in the dashboard interface, was intended to improve user-friendliness, especially for non-technical users such as citizens or municipal staff. It ensures that the platform does not require a background in energy modeling to understand the differences between scenarios and their implications.

Scenario Visualization Strategy

To make the comparison between scenarios both intuitive and informative, we implemented several visualization techniques in Google Looker Studio:

- **Bar Charts** were used to provide a quick comparative view of production and consumption across the three scenarios. This format allows users to identify imbalances or improvements at a glance, especially in terms of how much local renewable production can meet local demand.
- **Score Cards** (a native Looker feature) were used to display key performance indicators, Self-Consumption Index (SCI), Self-Sufficiency Index (SSI), and Overproduction Index (OPI), in a numeric and contextualized format. Rather than simply showing a percentage, each score card includes a short explanation in plain language (e.g., "% of energy used where it's produced"), ensuring interpretability across stakeholder groups.
- A "Best Scenario Highlight" section automatically identifies the best-performing scenario for each municipality based on specific energetic indicators. This section features:
    - A green marker for best energy independence,
    - A blue marker for best local energy usage, and
    - An orange marker for least excess energy production.

The filters were designed to help users quickly get a sense of which energy-sharing scenario works best for their specific municipality. Whether someone is a local policymaker or just a normal resident, they can easily compare different options without feeling overwhelmed by numbers.

To make navigation smoother, I added interactive tabs that let users switch between different categories of indicators. then, the dashboard focuses mainly on energy-related data, but the structure was built with future flexibility in mind. If and when data on economic, environmental, or social factors becomes available, it can be added without needing a complete redesign.

One of the most useful features is the use of Google Maps. This allows users to actually see where each municipality is located, giving more context to the numbers. It's not just about performance metrics, it is also about understanding how energy trends are distributed across the territory, which is this case, municipalities.

By using Google Looker Studio, I was able to keep everything running smoothly. The dashboard pulls its data from Supabase, which uses PostgreSQL under the hood. This setup keeps loading times very fast, even when working with big datasets covering hundreds of municipalities and multiple scenarios and rows. It's also built to be responsive, so whether someone's checking it on a desktop, tablet, or smartphone, the layout adjusts automatically to stay clear and easy to use. This was especially important for making sure the platform works well for people in the field, like technicians or local officials, who may be accessing it while on the move.

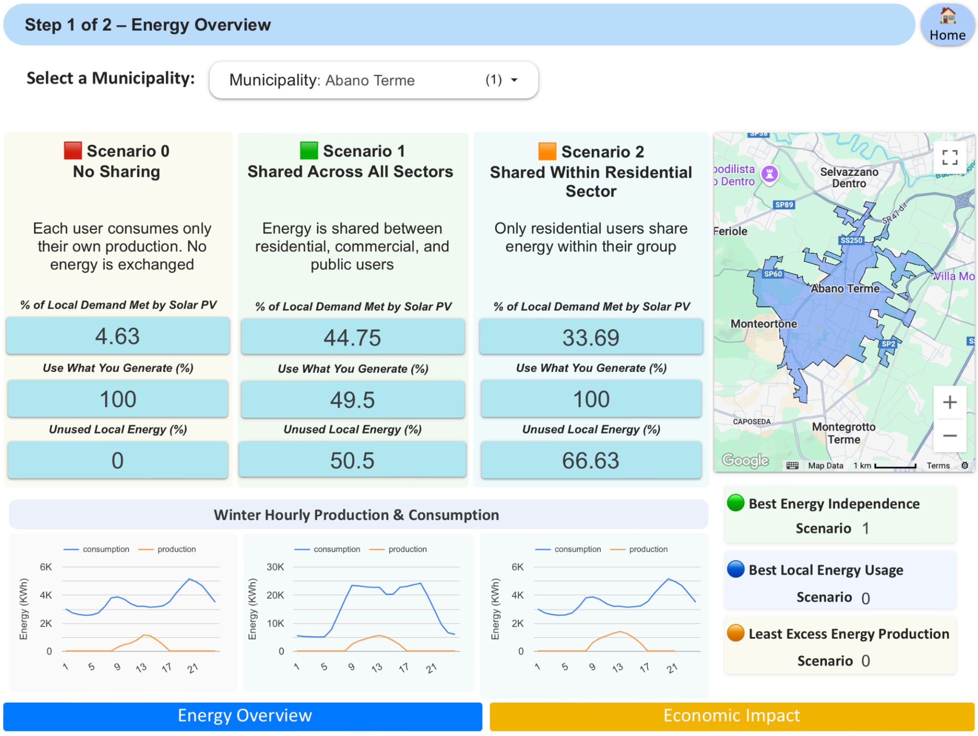

Figure 6: Energy Overview for Policy Bodies, Citizens and Private Sectors

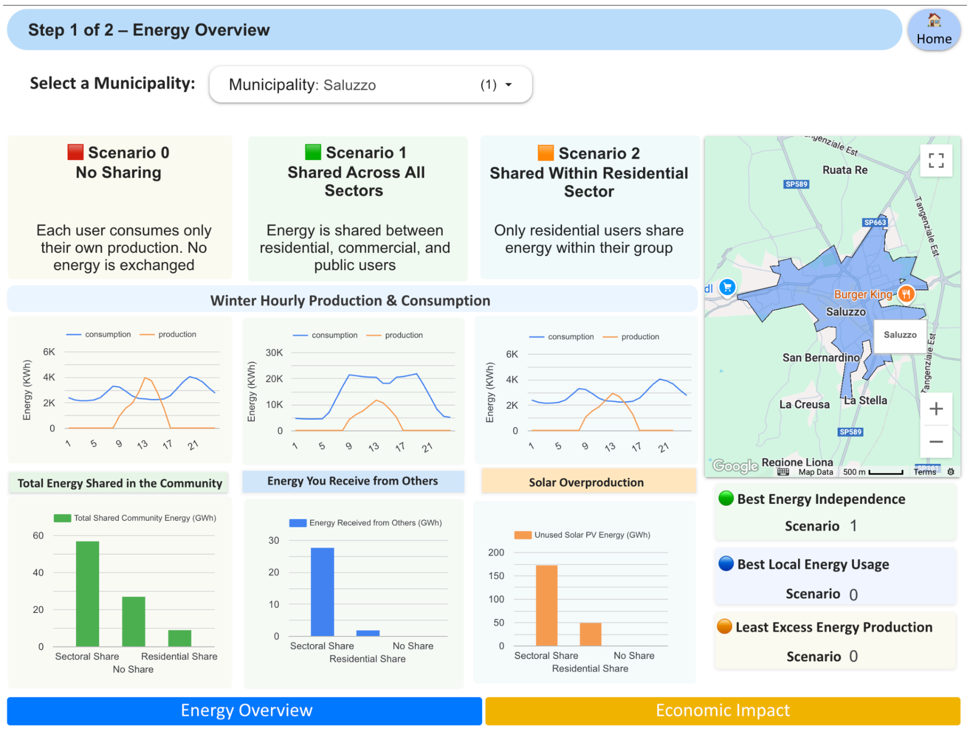

Figure 7: Energy Overview for Energy System Operators and Utilities

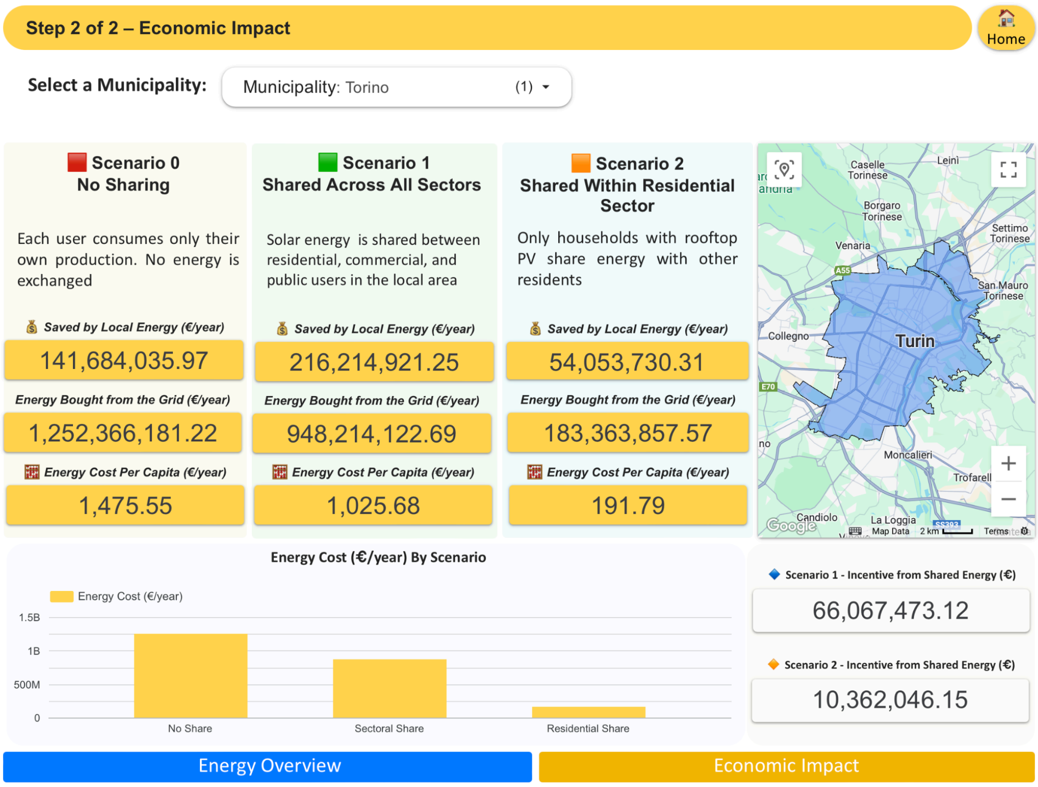

Figure 8: Economic Overview for All Stakeholders

4.4 Indicator Definitions

To ensure the validity and reproducibility of the indicators used in this platform, this section outlines the key energy and economic metrics implemented in the interface, their calculation logic, and the official sources from which the assumptions are derived. All indicators were selected and computed based on national standards, regulatory documents, and average Italian market prices as of early 2025. Since the platform includes data from over 7,800 Italian municipalities, a simplified but realistic approach was adopted to ensure comparability and usability across the national scale.

4.4.1 Energy Indicators and Their Meaning

The main energetic indicators calculated and visualized in the platform are:

- **% of Local Demand Met**: Share of total energy demand that is met by local renewable production.
  Formula:

- **Use What You Generate**: portion of the local solar PV energy production that is consumed within the community.

Formula:

- **Unused Local Energy**: The share of produced energy that is not used locally and then is injected into the grid.
  Formula:
  Total Local PV Production−Locally Consumed Energy

These indicators are designed to in order to help local bodies, communities, municipalities, and prosumers, make them understand the efficiency of local energy generation and the level of self-sufficiency achieved.

4.4.2 Economic Indicators and Calculation Assumptions

To assess economic viability and community-scale impacts, the following indicators were used:

User-Friendly Label	Formula	Explanation
Saved by Local Production	Self-Consumption × 0.3128 €	Electricity used locally × residential tariff (€0.3128/kWh) = savings from avoiding grid purchase
Energy Bought from the Grid	Uncovered Local Demand × 0.3128 €	Uncovered Local Demand × residential tariff = cost of imported energy
Revenue from Sold Energy	Overproduction × Regional RID Tariff	Energy sold to the grid at average regional Ritiro Dedicato (RID) rate: Nord ~0.107 €/kWh, Center ~0.104 €/kWh, Rest ~0.099 €/kWh
Incentive from Shared Energy	collective self-consumption× Regional TIP Tariff	Incentive based on shared energy (TIP): Nord = 0.130 €/kWh, Center = 0.124 €/kWh, South = 0.120 €/kWh (plants ≤200 kW)
Energy Cost per Capita	(Energy Bought - Revenue from Sold Energy - Incentive from Sharing) ÷ Population of each municipality	Total cost distributed across users

Table 13: Economic Indicators Description

4.5 Scalability, Limitations and Future Integration

Despite the structured planning, the methodology in the previous chapter and stakeholder-driven design of the interface, not all envisioned and desired indicators and visualizations methods in the methodology could be fully implemented in the final interface. Several key challenges emerged during development of the dashboard, including restricted access to confidential datasets from ENEA, such as detailed energy poverty metrics or financial return data), inconsistencies in municipal-level data coverage, and the lack of real-time or hourly energy flow data. These limitations have led to the exclusion of some indicators or simplification of certain indicators across stakeholder dashboards. Nevertheless, the platform was built to remain modular and scalable, allowing future integration and certain improvements of the omitted elements as more comprehensive data, especially those financial metrics becomes available.

The current architecture of the platform is designed to be scalable and future-proof, supporting both the addition of new indicators and the integration of real-time data sources. Since all datasets are stored in Supabase, which operates on a PostgreSQL backend, any updates to the underlying tables, whether manual or automated, are immediately reflected in the dashboard through live querying in Google Looker Studio. The normalized structure of the data (long format) further facilitates scalability, as new data points (e.g., from additional municipalities, time periods, or real-time sources) can be inserted without altering the dashboard schema or logic.

This structure allows future administrators or developers to integrate real-time data pipelines, such as through API endpoints, automated scripts, or webhooks, that populate the Supabase tables continuously. PostgreSQL's robust performance enables efficient handling of large datasets with minimal latency, making the system well-suited for ongoing energy monitoring and responsive planning.

In addition, the platform was intentionally designed with stakeholder adaptability in mind. Each visualization element, whether scorecard, map, or filter, is modular and can be tailored to the needs of different user groups. This allows future versions of the dashboard to offer customized views for municipalities, REC members, utilities, investors, or citizens, without requiring changes to the backend structure. The role-based layout introduced in the current version lays the groundwork for further expansion and targeted communication.

Finally, the architecture supports geographic scalability: by expanding the dataset to include regional or national records, the same framework could power dashboards for wider policymaking or comparative territorial analysis. Taken together, these structural and architectural choices ensure that the interface is not only a responsive tool for today's REC performance evaluation, but also a flexible, long-term instrument for data-driven energy governance.

Chapter 5: Discussion

This section assesses how effective and user-friendly the Renewable Energy Communities (REC) Dashboard created in this thesis is. The earlier chapters outlined the justification, methodology, and technical specifics; here, the interface is examined critically from the perspective of its target users. In particular, this analysis evaluates whether the interface truly enables local authorities, citizens, grid operators, and financial stakeholders to make informed, data-based decisions regarding renewable energy planning and investment.

5.1 Stakeholder Engagement and Interpretation

The dashboard's key strength lies in its tailored design, with distinct views customized for each stakeholder type:

- **Local & Regional Authorities:** Authorities can quickly assess local energy independence (% Local Demand Met by Solar), grid dependency, and economic impacts. Simplified terminology such as "Use What You Generate" helps translate complex metrics into actionable insights. The geographical context provided by interactive maps allows policy planners to identify regional strengths and areas needing intervention, directly aligning with EU climate goals.
- **Citizens**: For individuals like ordinary residents, emphasizing tangible benefits like yearly savings on energy costs clearly illustrates the financial perks of joining a Renewable Energy Community program. The straightforward depiction of hourly energy generation and consumption patterns aids in comprehending daily energy usage, which can lead to behavioral changes such as shifting consumption habits or investing in energy storage options.
- **Energy Grid & Utility Managers**: Hourly energy profiles enable energy grid managers to observe peak demand periods and recognize times when there may be surplus production. This time-based information aids in efficient grid management, particularly in the planning of infrastructure investments such as energy storage and load-balancing strategies.
- **Private Sector and Investors:** Financial stakeholders benefit from indicators directly related to economic feasibility and return on investment. The dashboard clearly visualizes critical financial metrics (e.g., energy savings, cost per capita), significantly reducing the complexity of assessing financial viability across various energy-sharing scenarios.

5.2 Review of Interface Effectiveness and Accessibility

- **Role Selection Screen**
  By dividing users based on their role, such as citizens, public administrators, or energy providers, the entry point felt straightforward and approachable. The use of descriptive images and short labels can help most people understand where to begin.

That said, a few users still hesitated before selecting their profile, unsure which category fit best. It might help to add small on-screen hints or short explanations that appear when hovering, just to ease that initial uncertainty.

- **Energy Overview Page**
  The comparative layout used here turned out to be quite effective. Displaying the same indicators across different energy-sharing scenarios helps people grasp differences visually, without having to read much. Still, there's room for improvement. Sometimes it is not always obvious which scenario performed **best** for a given indicator. A subtle visual cue or label could help draw attention to those differences more clearly. Additionally, brief pop-up explanations, activated on hover, might help clarify terms for users who aren't familiar with energy planning.
- **Economic Impact Page**
  Translating complex energy indicators into more familiar financial terms, like yearly savings or cost per person, made the data feel more relevant to everyday life. The ability to see figures "per capita" also helps users relate the information to their own situation. However, when certain values turn out to be negative (for instance, in cases of overproduction or when estimating energy purchased from the grid), some users can be confused. A short sentence or note next to these values would go a long way in preventing misinterpretation, especially for people seeing this kind of data for the first time.

5.3 User Experience and Visual Presentation

- **Visual Consistency and Clarity**

During testing, the use of consistent color coding, red for "no sharing," green for "shared among all," and orange for "residential sharing only", proved helpful in reinforcing the structure of the dashboard. After spending a few minutes with the interface, most users no longer needed to refer back to the legend; the color scheme became intuitive and made it easier to navigate across different pages. That said, not everyone found the contrast between these colors strong enough. A few users with visual impairments mentioned difficulty distinguishing between the orange and red, particularly in smaller charts. Adjusting the saturation or brightness levels of these colors could make them more distinguishable. Alternatively, placing brief textual tags inside or next to each visual element, for example, "No Sharing" or "Residential", might improve legibility without disrupting the overall design. These small tweaks could make a meaningful difference for accessibility while keeping the interface visually coherent.

- **Device Responsiveness and Ease of Use**

The platform held up well when used on larger screens. On laptops and tablets, transitions were smooth, and the layout maintained a clear visual hierarchy. However, the mobile version still has room for improvement. On smartphones, especially, the density of information sometimes overwhelms the available screen space. Long text blocks, combined with multiple charts stacked vertically, forced users to scroll extensively, which could become tiring or confusing. One idea that emerged from feedback was to introduce collapsible sections, allowing users to open and close specific categories like “Economic Indicators” or “Scenario Comparison” as needed. This would make the experience more manageable, particularly when on the go or accessing the platform in low-bandwidth situations. Streamlining the content for mobile use, without removing it, could strike a balance between completeness and usability.

5.4 Technical Performance and Scalability

The dashboard demonstrates high technical robustness through rapid querying and responsiveness, even when managing complex data for over 7800 municipalities. The backend infrastructure (Supabase and PostgreSQL) ensures data integrity, quick filtering, and real-time updating capabilities, supporting future scalability and the integration of real-time data streams.

Importantly, the architecture developed using Supabase and PostgreSQL has inherent support for real-time data integration. Future updates can easily incorporate live data through automated data pipelines, APIs, and webhook integrations, enabling the dashboard to provide up-to-date information dynamically. While the current implementation in Google Looker Studio has some limitations regarding real-time streaming, upgrading to other business intelligence tools or advanced plugins can effectively overcome this, positioning the dashboard to become fully real-time responsive.

5.5 Alignment with Literature and Best Practices

Throughout the design process, careful attention was paid to aligning decisions with established research and recognized design principles. The use of time-based visualizations, as an example, draws on insights from Wilson (2016), who emphasized the importance of showing temporal change to help users understand energy trends and flows over time. Similarly, the structure of information, beginning with high-level overviews and allowing users to explore more detailed layers, reflects in a good way, the approach suggested by Chen and Chen (2021), which suggests making the most relevant information immediately visible while keeping deeper analytics easily accessible.

Also, the focus on scenario-based comparisons responds directly to a recurring gap in the literature: the need for better communication tools to help non-expert audiences grasp the impact of different energy strategies. As mentioned before by Billger et al. (2016), many platforms fall short when it comes to helping the public engage with complex energy data. This dashboard aims to fill that gap by making comparative scenarios both intuitive and interactive.

5.6 Strengths and Contributions

- A few significant additions to the larger discussions on renewable energy planning are made by this work, particularly when considering community-based energy projects and local governance.
- Local Granularity with Scenario Flexibility: Its capacity to model and evaluate various sharing situations with municipal-level precision is one of its most significant characteristics. This closes a notable gap in the tools that are now available, which frequently overlook the subtleties of local planning in favor of national or regional dimensions.
- Designed for People, not just Data: A significant advantage is the design that is guided by stakeholder input. From the outset, the interface was created to address the genuine and specific needs of various user groups, including policymakers, citizens, and grid operators, utilizing language and visuals customized for each. This approach has enhanced the platform's accessibility and relevance for a diverse audience.
- Scalable, with an Eye on the Future: While the existing dashboard relies on static datasets, its design is prepared to support real-time data in future enhancements and functionalities. This allows it to be flexible, catering to both expanding datasets and the changing requirements of policy and energy markets.

5.7 Limitations and Future Development

While the project lays a solid foundation, it's important to know its limitations and consider how the platform can continue to evolve.

- **Fixed Energy Pricing**: At present, the dashboard relies on static pricing assumptions, which simplifies economic calculations but doesn't fully capture the dynamic nature of real-world energy markets and prices. Incorporating real-time pricing feeds would allow users to model scenarios that reflect current market conditions more accurately.
- **Limited Feedback Features**: Although the dashboard is designed with users in mind, there's currently no built-in way to collect user feedback or track how the tool is being used and satisfied users. Adding these features would enable more responsive updates and a better understanding of how the dashboard supports decision-making in practice.
- **No Side-by-Side Comparisons**: Lastly, users are limited to exploring two or more municipalities at a time. Enabling side-by-side comparisons would significantly enhance the platform's usefulness and abilities ,especially for local administrators looking to benchmark performance or evaluate the impact of different strategies across similar communities and cities

5.8 Final Reflection

The REC Dashboard has successfully demonstrated its capacity as an effective decision-support tool, clearly bridging the gap between complex renewable energy data and actionable insights for diverse stakeholders. While this thesis established a solid foundation in visualization design, stakeholder-specific functionality, and technical robustness, future research could further enhance its capabilities by incorporating additional social equity indicators, environmental impact metrics, and real-time data feeds. Ultimately, the dashboard stands as a valuable prototype and a replicable model, capable of significantly contributing to sustainable energy transitions both within Italy and globally.

Chapter 6: Conclusion and Future Work

What this platform ultimately offers is a way for local communities to make sense of something that's often too technical to engage with, energy data. By combining geographic context with actual figures on production, consumption, and costs, it becomes easier for different stakeholders to explore what joining a Renewable Energy Community might mean in practice. Whether it's a policymaker needing to plan future investments or a citizen simply curious about solar potential in their area, the interface presents the information in a way that feels accessible and grounded. This was the core ambition from the beginning: not just to visualize data, but to build a bridge between numbers and real-life decisions. The result is a tool that can be used in formal decision-making processes, but also one that can invite broader participation, opening the door to more democratic and locally-driven energy planning.

6.1 Limitations

Despite illustrating great promise, the current version of the interface does not yet allow real-time updates and is dependent on static data for a small number of scenarios. Additionally, the interface's relevance and usability could be improved with additional field validation through user testing and feedback, even though important indicators were carefully chosen based on policy standards and literature. Moreover, additional renewable energy sources like wind and biomass are not yet included in the current prototype, which primarily uses solar power.

6.2 Future Work

When the development of the dashboard started, the primary focus was based mostly on getting the first version to work. Now that the prototype is finished, several clear next steps have emerged.

Bringing in live data.
Right now, the platform runs on annual and hourly figures that updates by hand. Hooking it up to a real-time feed, perhaps through a lightweight service like Supabase or a small custom API, would let community managers see what is happening in the network from one hour to the next and act on that information immediately.

Adding other renewables.
The current focus is solar because the case study area has good irradiation data. In many Italian regions, however, small-scale wind or biomass could play an equal or sometimes greater role even. Expanding the data model to include those sources would give local authorities a fuller picture of their options.

Listening to users.
So far, feedback has come from informal conversations. A more structured round of testing, short workshops with municipal staff, citizen cooperatives, and the local DSO, would tell us which charts are helpful, which are confusing, and where the wording needs to change.

Linking to policy targets.
National and regional plans such as the NECP and the local SEAP set measurable goals for energy savings and emissions. If the dashboard can read those targets and show progress against them, it will be far easier for officials to justify investments and track compliance.

Trying the method elsewhere.
Finally, the real test is whether the same approach works outside the pilot area. Re-running the workflow, data cleaning, indicator calculation, interface build, in a small Alpine municipality and then in a mid-sized city would show how well the tools scale and what has to be adapted.

Taking these steps would turn the dashboard from a promising prototype into a practical aid for communities that want to manage their own clean-energy future.

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