Assessment of Renewable Energy Communities : A Comprehensive Review of Key Performance Indicators

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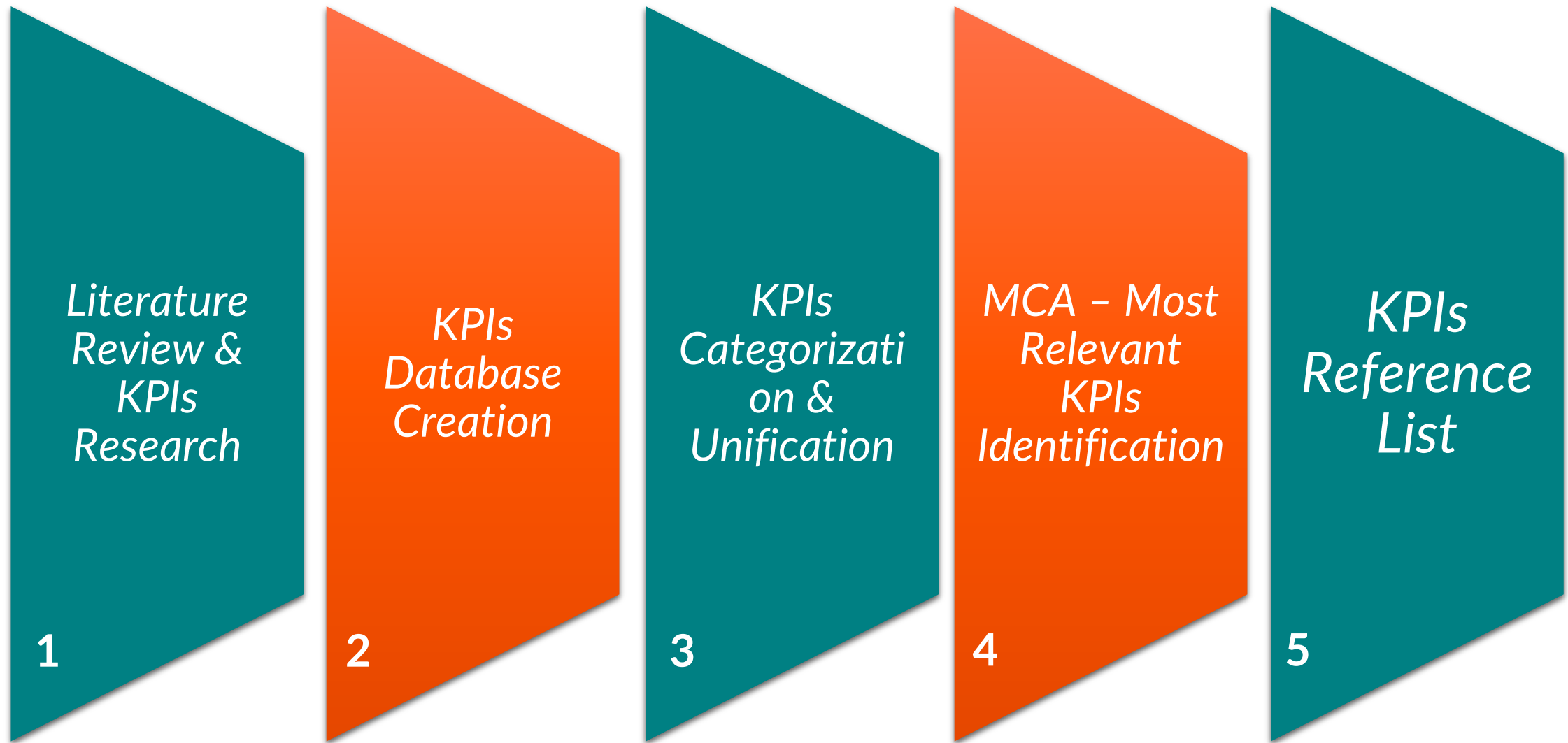[2] Department of Energy (DENERG), Polytechnic of Turin, Corso Duca degli Abruzzi 24, 10129 Turin, Italy
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- A detailed **research and analysis** of papers related to REC performance evaluation;

- **Extraction** of KPIs from relevant publications in a variety of multidisciplinary fields;

- A **sector-based categorization and classification** of KPIs across REC project phases;

- **Redefinition** of the KPIs by using a **common nomenclature**;

- An MCA to identify the **most suited KPIs** considering multiple domains and purposes;

- A **Reference List of 25 selected KPIs**, offering a toolkit to assess REC performance.

METHODOLOGY

1 Literature Review & KPIs Research

2 KPIs Database Creation

3 KPIs Categorization & Unification

4 MCA – Most Relevant KPIs Identification

5 KPIs Reference List

1) Literature Review & KPIs Research

The methodology of the systematic review includes a bibliographic search of research documents on REC analysis, the categorization of metrics based on their use, and the identification of key metrics.

The question driving our review is: "**What is the current state of the art in applying performance metrics to analyze RECs projects?**". The process is divided into four phases:

Papers Exploration 1.1

A comprehensive search of papers in the field of RECs using Scopus and Web Of Science databases
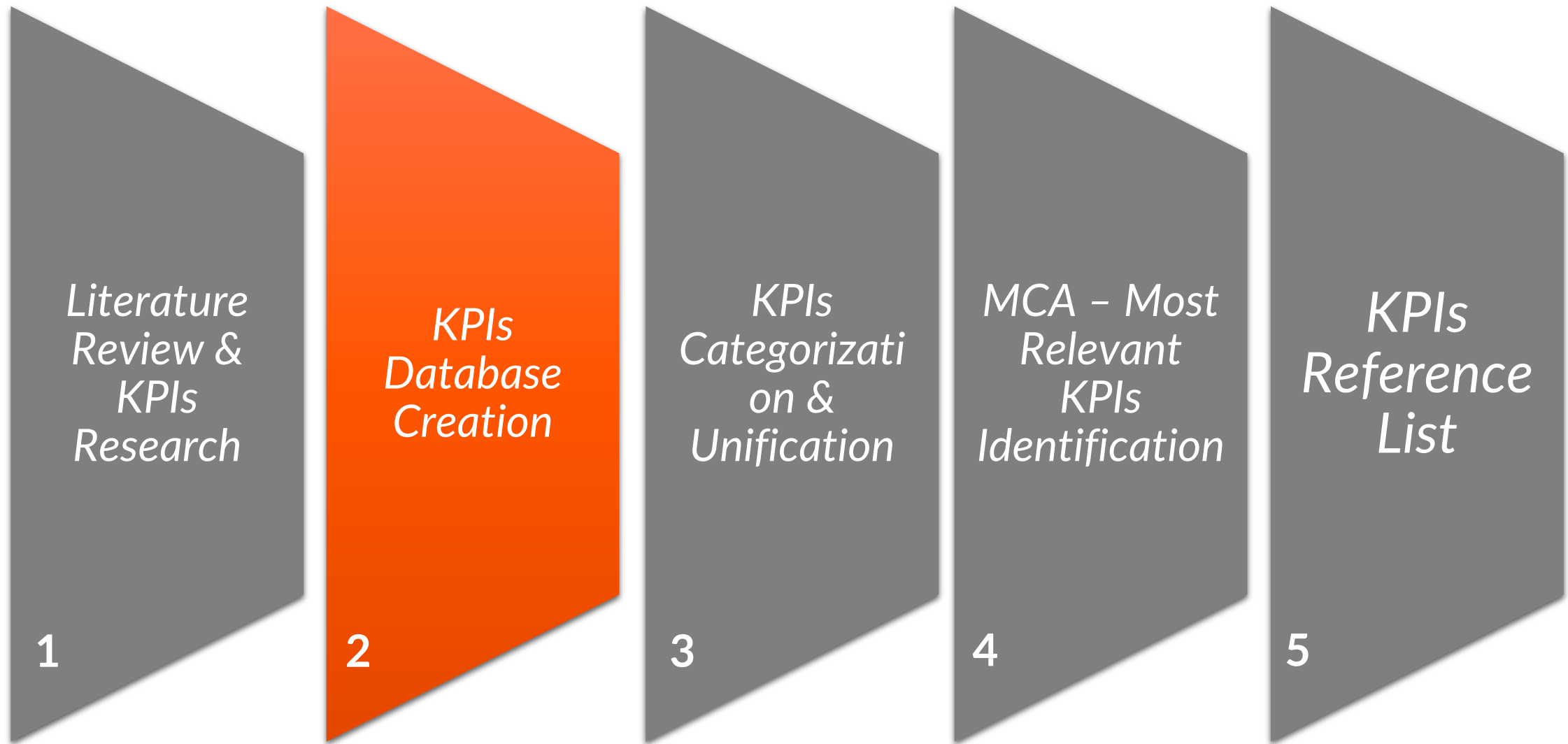
Papers Screening 1.2

Initial screening of collected literature based on research domain and accessibility

Papers Eligibility 1.3

Further filtering papers by extracting those that explicitly define KPIs through mathematical formulations in the context of the RECs.

Search Engines	Method	Query
Scopus	Article title, Abstract, Keywords	"key performance indicator" OR kpi OR "performance evaluation" OR indicator OR metric OR "performance metrics" OR "performance measures" AND "energy community" OR "community energy" OR "community institution*" OR "citizen* energy" OR "energy citizen*" OR "power to people" OR "citizen power plants" OR "cooperative energy" OR "energy cooperative" OR "power cooperative" OR "community-owned" AND local OR projects OR systems OR renewable OR sustainable OR integrated OR clean OR wind OR solar OR self-organized OR self-consumption
Web of Science	All field	

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1 — Literature Review & KPIs Research

2 — KPIs Database Creation

3 — KPIs Categorization & Unification

4 — MCA – Most Relevant KPIs Identification

5 — KPIs Reference List

Papers Exploration — 1.1

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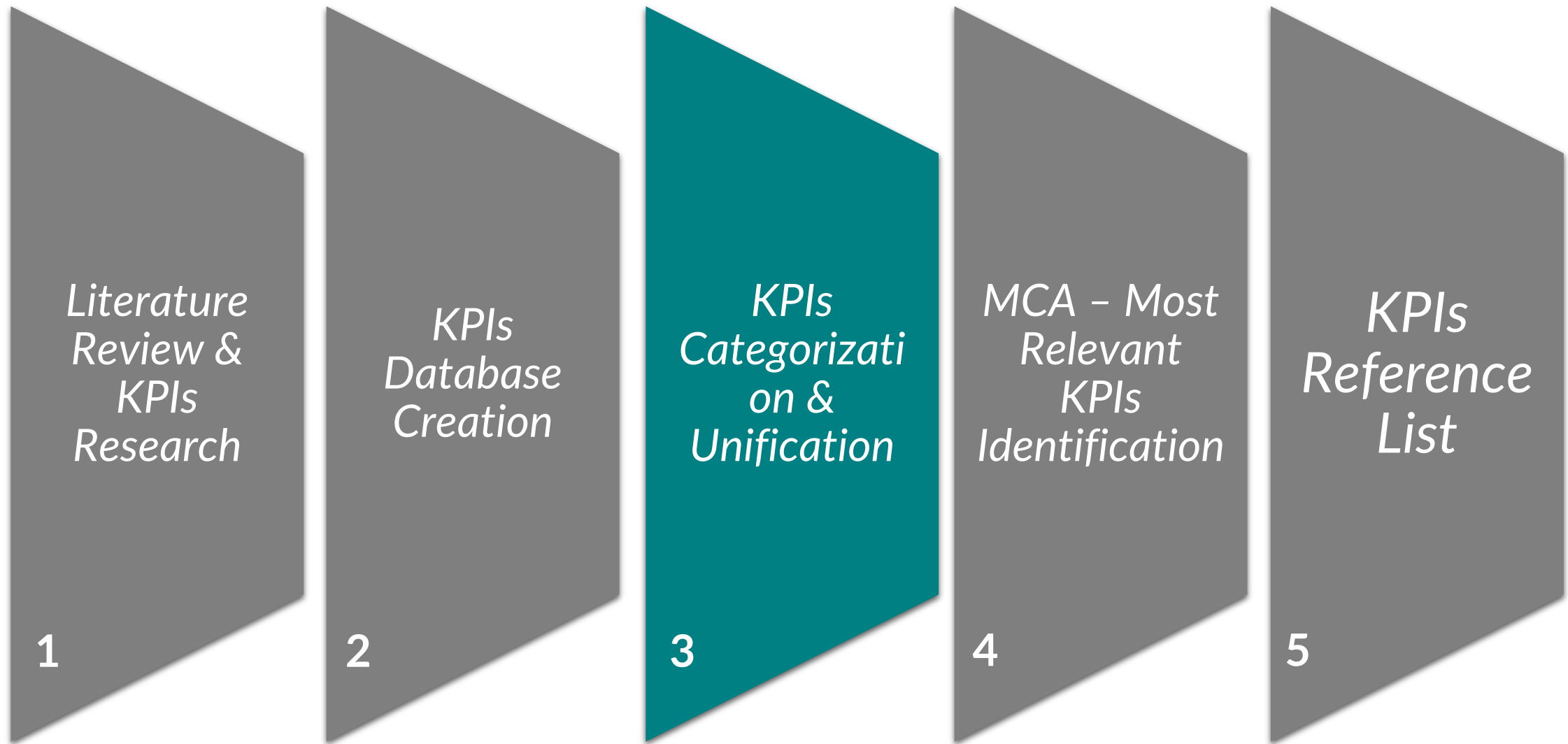
Papers Eligibility — 1.3

Further filtering papers by extracting those that explicitly define KPIs through mathematical formulations in the context of the RECs.

KPIs Database

KPIs extracted from the papers identified in the *Literature Research* are systematically collected and organized:
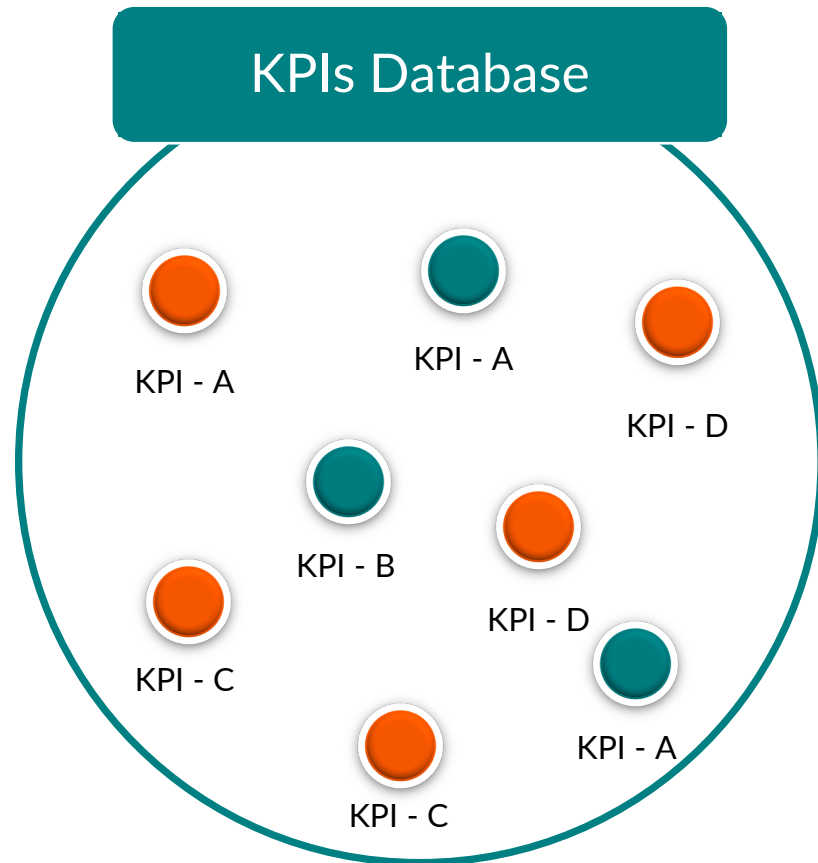
1) **Definition** and the **mathematical formula**;

2) **Sector Domain** – specific areas in which a REC operates. Four domains are considered (energy, economic, environmental, and social);

3) **Usage** – categorizes the purpose for which a KPI was used in the literature (planning, operation, benchmarking, monitoring);

4) **Type** – Specifies whether the KPI is numeric or categorical (e.g., boolean indicators that reflect the presence or absence of specific characteristics within the REC);

5) **Target** – Identifies the specific stakeholders for whom the KPIs are intended, providing insight into which groups or entities would benefit from visualizing these KPIs;

6) **Control Volume** – Defines the physical boundaries within which data must be known to calculate the respective KPIs, providing a quick and immediate indication of the perimeter of the analysis when evaluating performance metrics.

Literature Review & KPIs Research

1

KPIs Database Creation

2

KPIs Categorization & Unification

3

MCA – Most Relevant KPIs Identification

4

KPIs Reference List

5

The *KPIs Categorization and Unification* phase focuses on **grouping and uniforming similar KPIs**, assigning them a single mathematical definition.
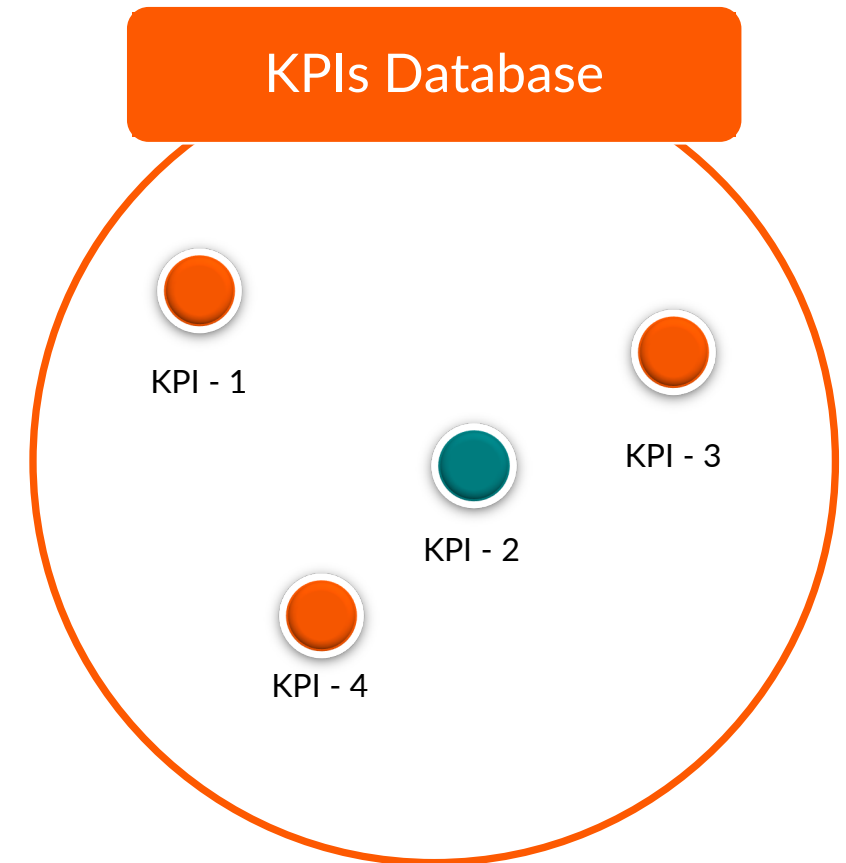

1. **Equality** – KPIs that share the same mathematical definition, and depend on the same variables. Two or more KPIs are deemed equal if they are mathematically equivalent.
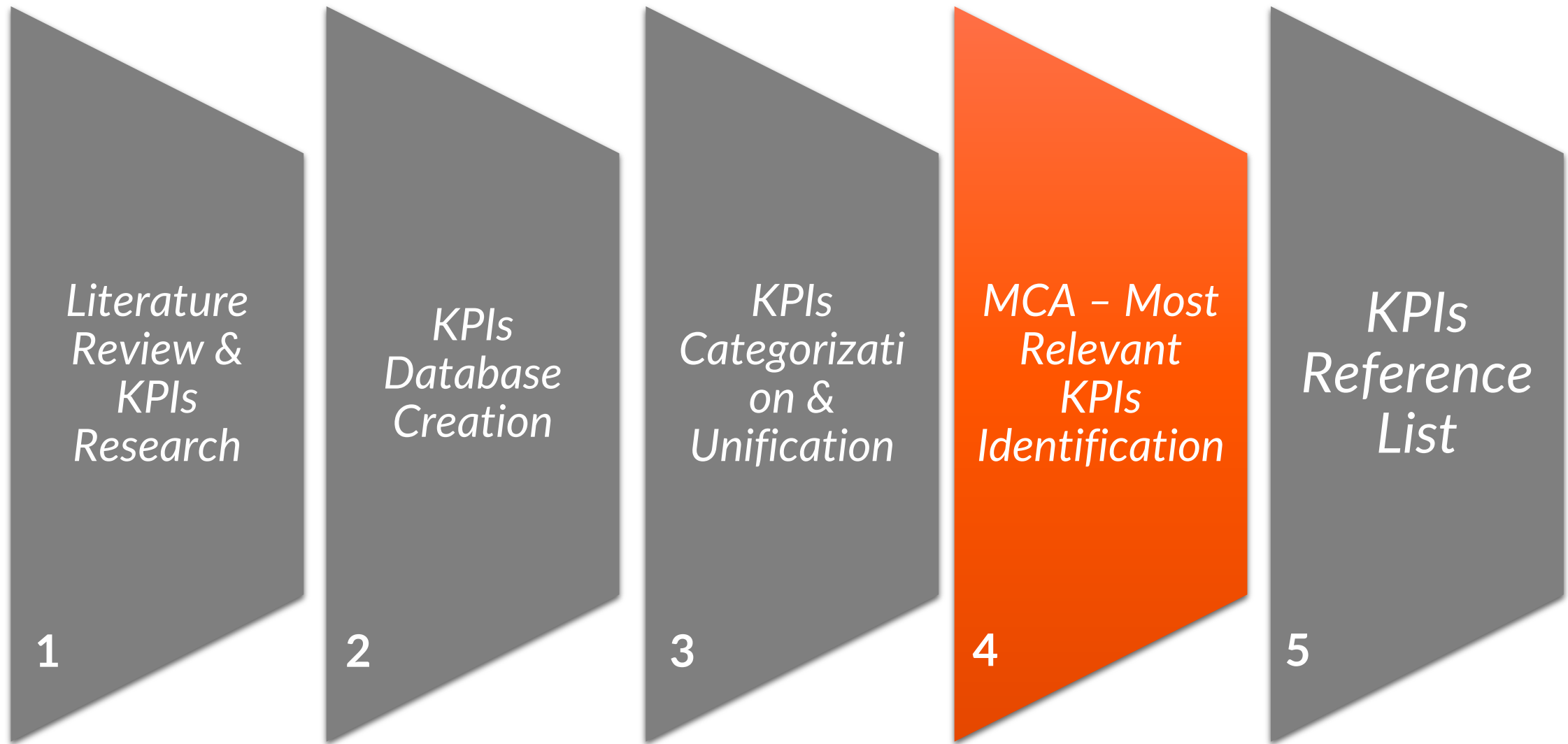
2. **Similarity** – KPIs that express the same concept and depend on the same variables but have slightly different formulations.

3. **Relatedness** – KPIs derived from other KPIs and convey equivalent information. These KPIs are functions of other KPIs, involving basic arithmetic operations such as ratios, multiplication, addition, or subtraction.

4. **Uniqueness** – KPIs that do not conform to the previous criteria are categorized as unique.
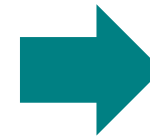
Literature Review & KPIs Research

1

KPIs Database Creation

2

KPIs Categorization & Unification

3

MCA – Most Relevant KPIs Identification

4

KPIs Reference List

5

The identification of most relevant KPIs is guided by a Multi-Criteria Analysis (MCA). For each **Sector Domain**, the KPIs are evaluated based on the following criteria:
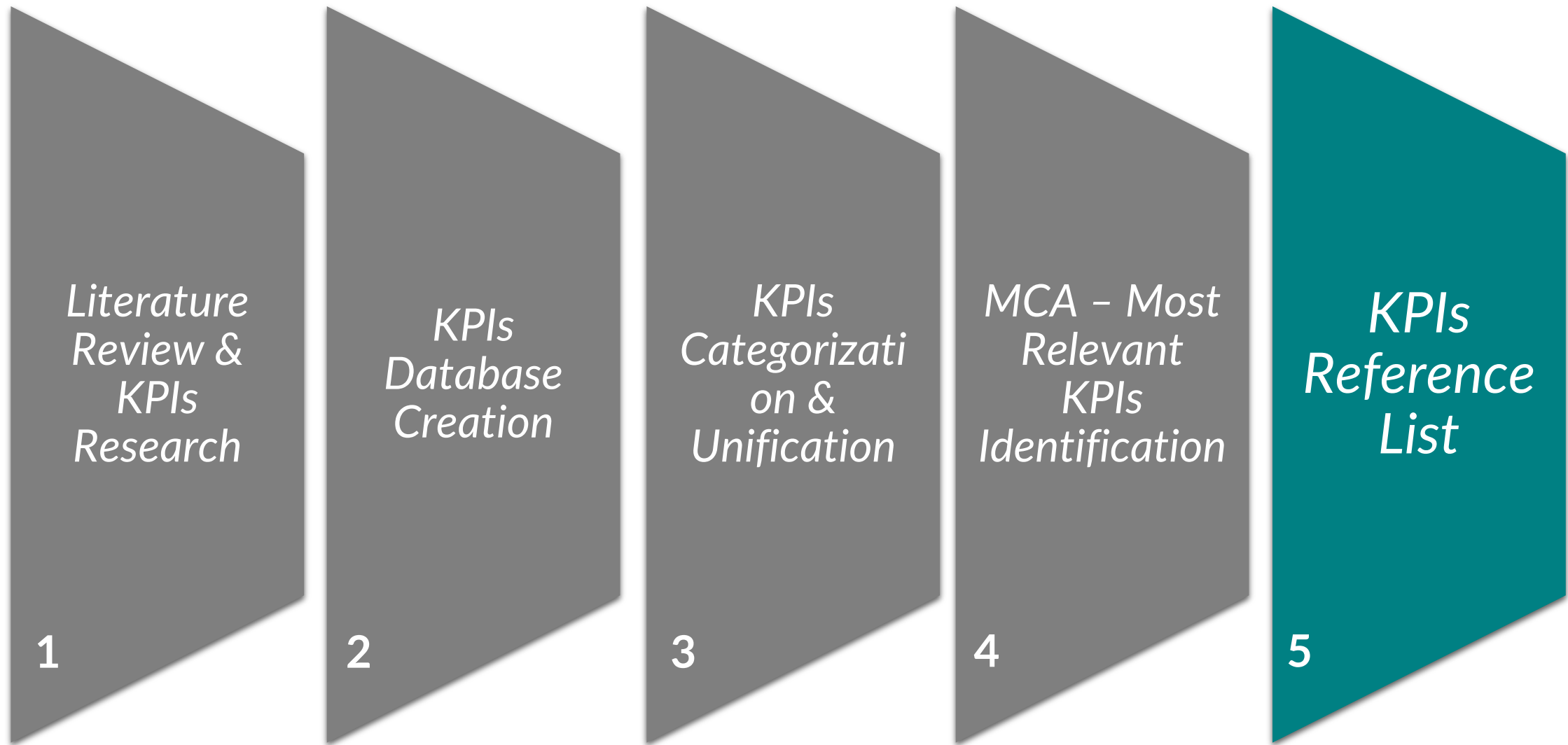
❖ **Frequency (F)** – The number of times the aggregated KPIs appear with mathematical formulations in the analyzed articles;

❖ **Usages Coverage (UC)** – The number of different Usages for which the aggregated KPIs were applied;

❖ **Targets Coverage (TC)** – The number of different Targets to which the aggregated KPIs are addressed.

Score	Frequency	Usages Coverage	Targets Coverage
0.25	from 1 to 8	1 out of 4	1 out of 4
0.50	from 9 to 14	2 out of 4	2 out of 4
0.75	from 15 to 21	3 out of 4	3 out of 4
1.00	greater than 21	4 out of 4	4 out of 4

$$MCA_{score} = w_1 * F + w_2 * UC + w_3 * TC$$

Energy KPIs

KPI	Formula	UC	TC	F	MCA Score
Electrical Self - Production Rate (ESP)	$ESP = \dfrac{E_{el,prod}}{D}$	1.00	0.75	0.50	2.25
Total Energy Used (TEU)	$TEU = \sum_{t=1}^{T}(E_{fg,t} + E_{prod,t})$	1.00	0.75	0.5	2.25
Self - Consumption Rate (SCR)	$SCR = \dfrac{E_{el,self-cons}}{E_{el,prod}}$	0.75	0.50	0.75	2.00

Literature Review & KPIs Research

KPIs Database Creation

KPIs Categorization & Unification

MCA – Most Relevant KPIs Identification

KPIs Reference List

1 2 3 4 5

Based on MCA results and author's expertise in the field of RECs, **a set of 25 KPIs** constituting a structured framework for evaluating REC performances across energy, economic, social, and environmental domains, was created.

MCA Results

Energy KPIs

KPI	Formula	UC	TC	F	MCA Score
Electrical Self-Production Rate (ESP)	$ESP = \frac{E_{el,prod}}{D}$	1.00	0.75	0.50	2.25
Total Energy Used (TEU)	$TEU = \sum_{t=1}^{T}(E_{fg,t} + E_{prod,t})$	1.00	0.75	0.5	2.25
Self-Consumption Rate (SCR)	$SCR = \frac{E_{el,self-cons}}{E_{el,prod}}$	0.75	0.50	0.75	2.00

Economic KPIs

KPI	Formula	UC	TC	F	MCA Score
Annual Energy Cashflow (AEC)	$AEC = \sum_i Exp_i - \sum_j Inc_j$	0.75	0.75	1.00	2.50
Businesses Creation (BC)	$BC = N_{bus,REC}$	0.75	1.00	0.25	2.00
Capital Expenditure (CAPEX)	$CAPEX = \sum_i C_{i,0}$	0.50	0.75	0.25	1.50

Environmental KPIs

KPI	Formula	UC	TC	F	MCA Score
Environmental Impact (ENVI)	$ENVI = \frac{X_{poll,REC}}{X_{poll,ex-REC}}$	1.00	0.75	1.00	2.75
Low carbon Public Transportation Vehicles deployment rate (LPTV)	$LPTV = \frac{N_{LPTV}}{N_{REC\ public\ vehicles}}$	0.50	1.00	0.25	1.75
Noise Pollution Reduction (NPR)	$NPR = \frac{db_{REC}}{dB_{ex-REC}}$	0.50	0.75	0.25	1.50

Social KPIs

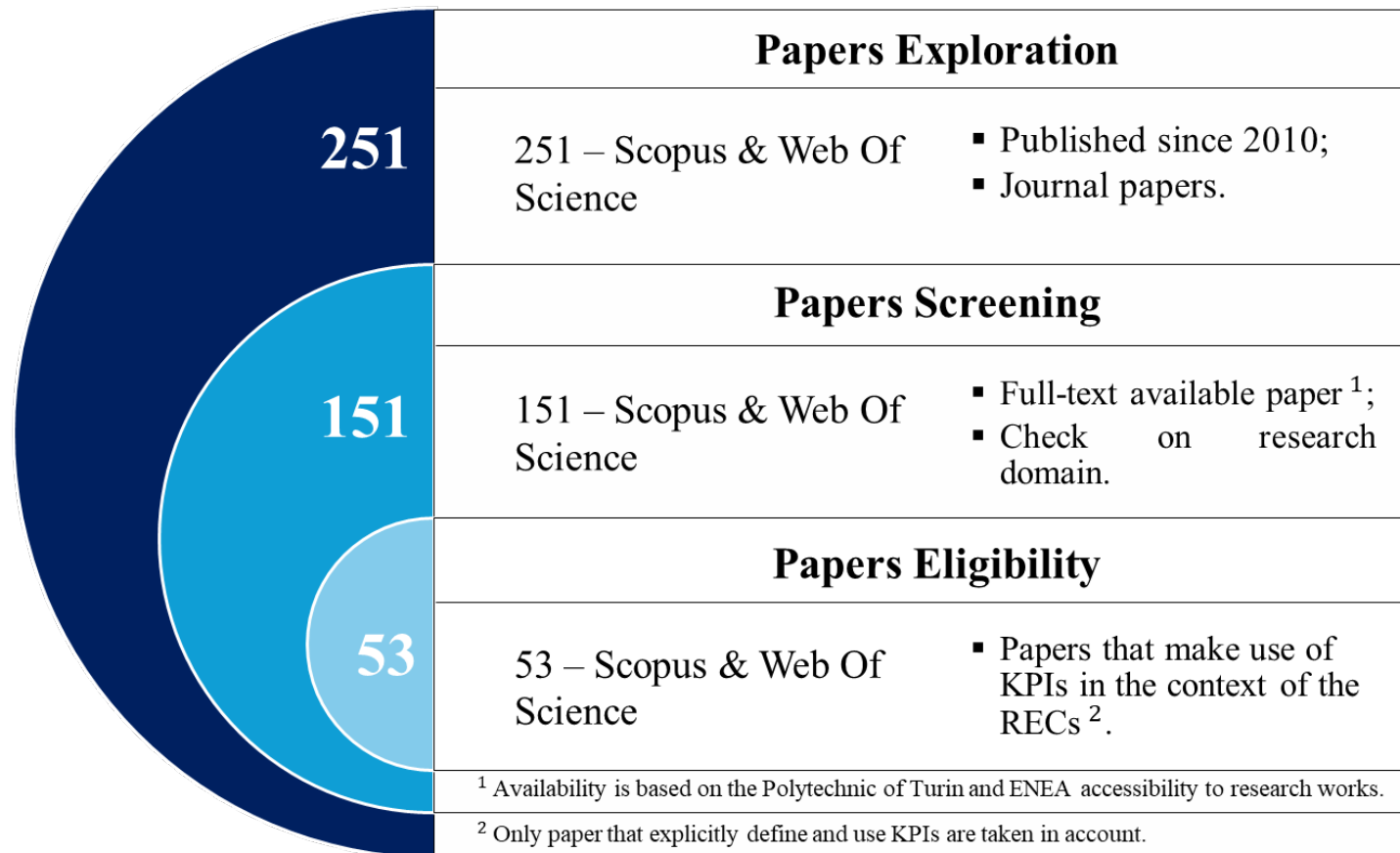| KPI	Formula	UC	TC	F	MCA Score
Local Representation (LR)	$LR = \frac{N_{rep,REC}}{N_{REC}}$	0.50	1.00	0.25	1.75
Social Energy Empowerment (SEE)	$SEE = \frac{N_{resp,REC}}{N_{REC}}$	0.50	1.00	0.25	1.75
Social Business Development (SBD)	$SBD = B_{EP} + B_{FP}$	0.50	1.00	0.25	1.75

Authors' Selection →

KPIs Reference List

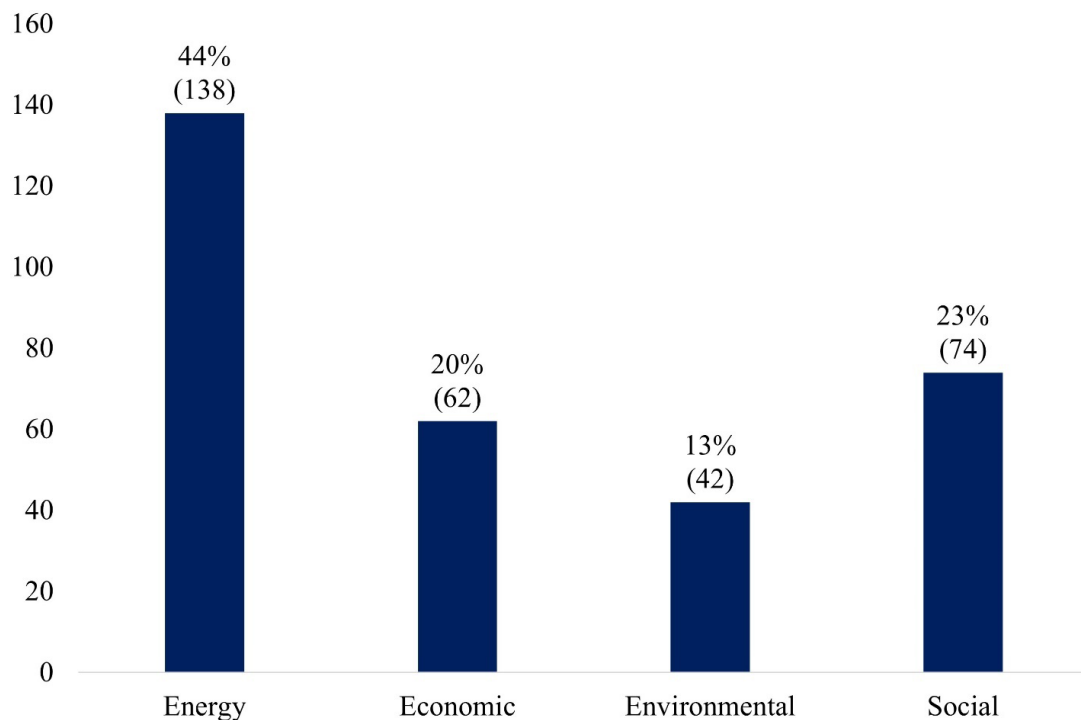| KPI	Sector Domain	Formula	Usage	Target	Control Volume
Shared Energy (SE)	Energy	$SE = \min(E_{fg}, E_{tg})$	Planning, Monitoring	REC, Policymakers, Stakeholders	REC-To-Grid
Payback Time (PBT)	Economic	$PBT = \frac{C_0}{Inc_y - Exp_y}$	Planning	REC, REC Members, Stakeholders	REC
GHG Emissions (GHGE)	Environmental	$GHGE = \sum_{i=1}^{T}(CO2_{eq,prod\,.t} + CO2_{eq,oper\,,t} + CO2_{eq,trans\,,t})$	Operation, Monitoring	REC, Policymakers	REC
Social Energy Empowerment (SEE)	Social	$SEE = \frac{N_{resp,REC}}{N_{REC}}$	Monitoring	REC Members	REC

RESULTS

The research on papers related to RECs and the use of KPIs to analyze their performance developed through the Literature Search phase, composed of **Papers Exploration**, **Papers Screening**, and **Papers Eligibility** sub-phases, led to the results shown in the following figure.

Papers Exploration	
251 – Scopus & Web Of Science	▪ Published since 2010; ▪ Journal papers.
Papers Screening	
151 – Scopus & Web Of Science	▪ Full-text available paper [1]; ▪ Check on research domain.
Papers Eligibility	
53 – Scopus & Web Of Science	▪ Papers that make use of KPIs in the context of the RECs [2].

[1] Availability is based on the Polytechnic of Turin and ENEA accessibility to research works.

[2] Only paper that explicitly define and use KPIs are taken in account.

Bar chart:
- Energy: 44% (138)
- Economic: 20% (62)
- Environmental: 13% (42)
- Social: 23% (74)

From the 53 identified papers, **316 KPIs** were extracted during the ***Database Creation*** phase. This set of KPIs includes **repeated or similar KPIs**, since this phase involves only collecting all the KPIs defined in the analyzed articles. Of these, 138 were classified as Energy (44%), 62 as Economic (20%), 42 as Environmental (13%), and 74 as Social KPIs (23%), as shown.
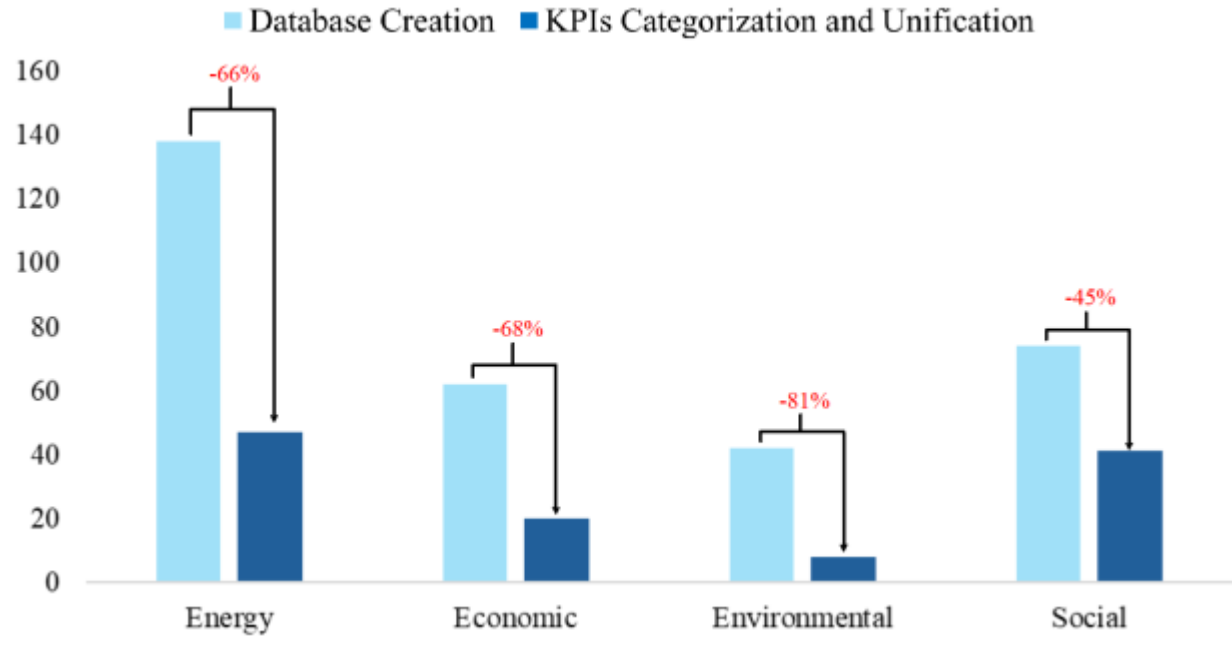
Among the 316 KPIs collected, the results show that the most frequent ***Usage*** is **Monitoring (36%)** and **Operation (31%)**, followed by Benchmarking (24%) and Planning (19%).

Usage	Frequency	Percentage
Monitoring	173	36%
Operation	151	31%
Benchmarking	69	24%
Planning	91	19%

KPIs UNIFICATION

Frequency by Sector Domain

Aggregation Criteria	Total Frequency	Energy	Economic	Environmental	Social
Uniqueness	60	35%	46%	44%	52%
Similarity	44	33%	29%	33%	33%
Relatedness	25	25%	13%	23%	13%
Equality	7	7%	12%	0%	2%

Energy KPIs experienced the most significant reduction in absolute terms, from 138 to 48. The number of **Economic KPIs** also dropped substantially, from 62 to 20, and **Environmental KPIs** saw a reduction from 42 to 7. In contrast, **Social KPIs** underwent a less drastic decrease, from 74 to 42.
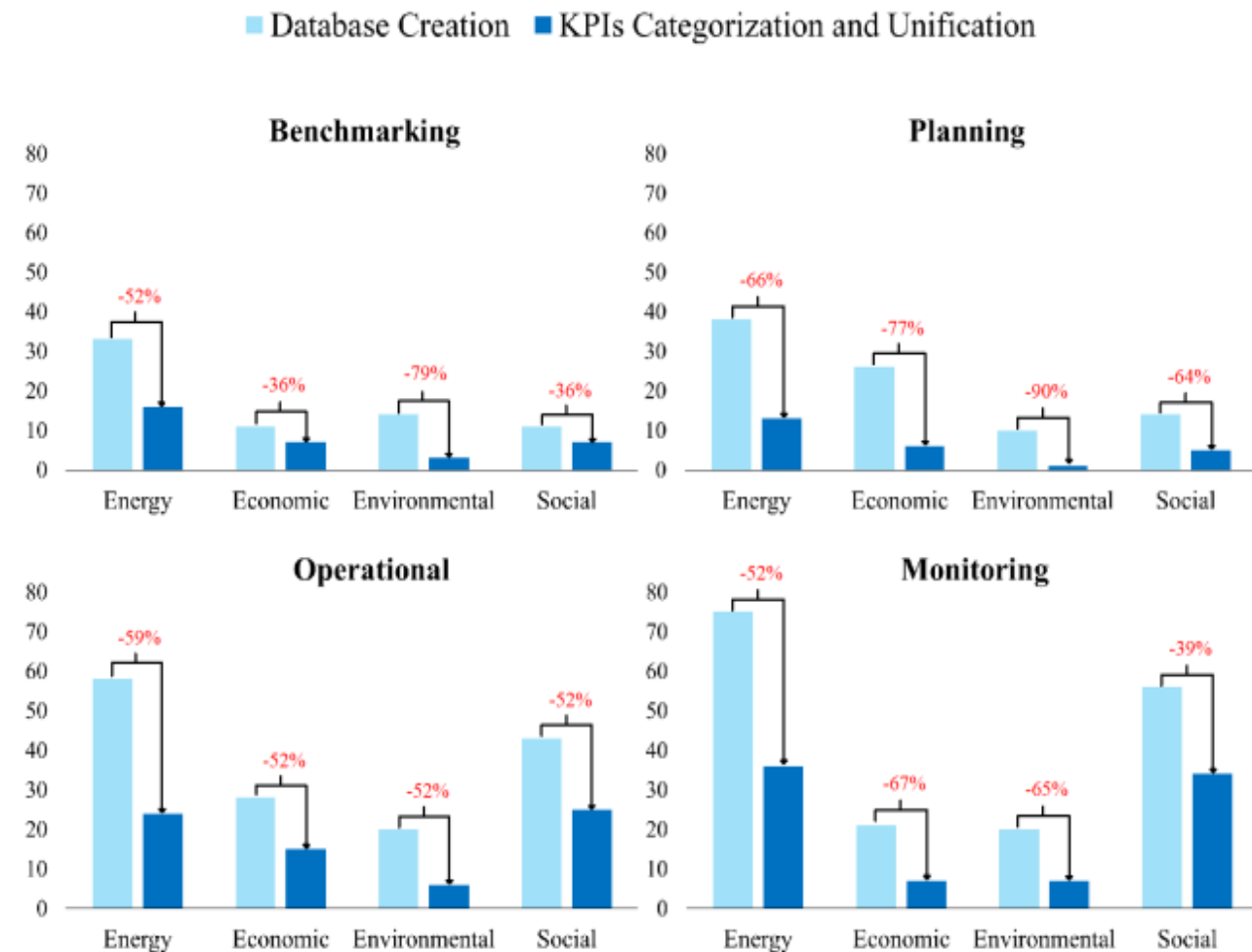
- **Energy KPIs**: The most impactful criteria are "uniqueness" (35%) and "similarity" (33%), followed by "relatedness" (25%). A small portion (7%) falls under "equality";
- **Economic KPIs**: The "uniqueness" criterion predominates (46%), while "similarity," "relatedness," and "equality" are less frequently used, each around 12-29%;
- **Environmental KPIs**: Notably, no KPIs were classified under "equality," and the other aggregation criteria were applied only a few times, reflecting the small number of environmental KPIs collected earlier.;
- **Social KPIs**: "Uniqueness" is also dominant here, accounting for 52% of the KPIs, with "similarity", "relatedness", and "equality" contributing 33%, 13%, and 2%, respectively.
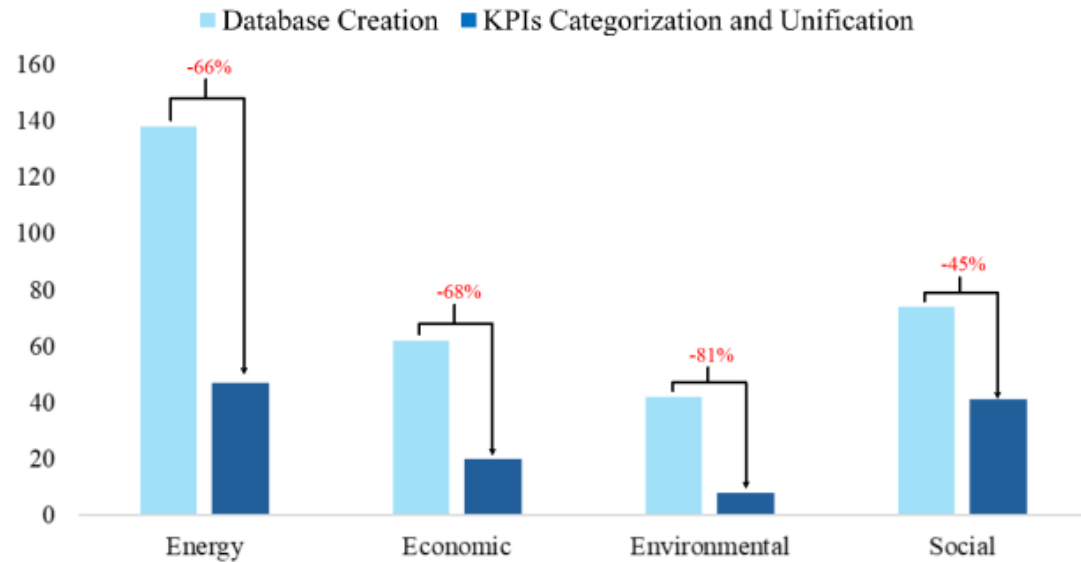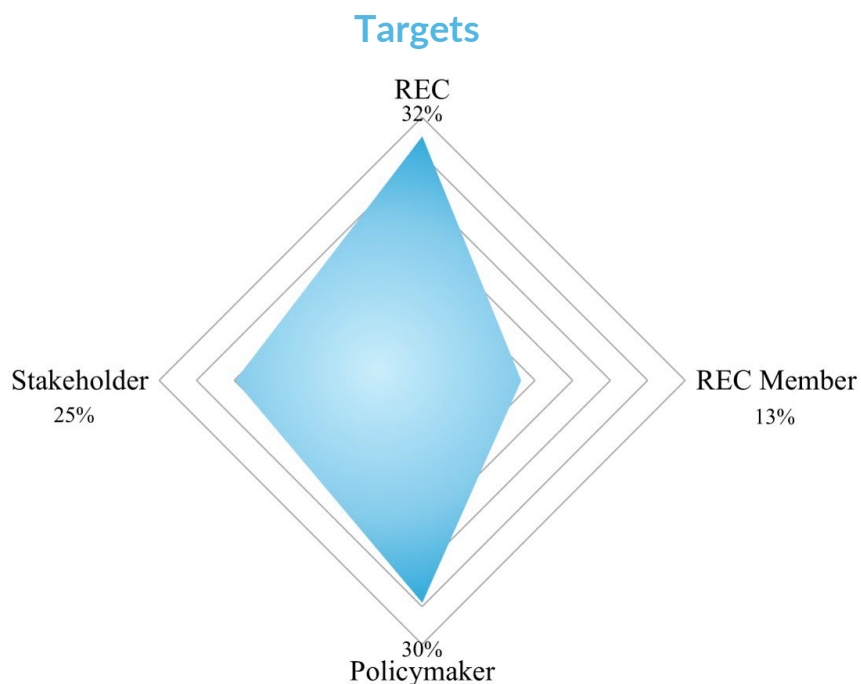
The aggregation process impacts KPIs across all **Sector Domains** and **Usages** fairly uniformly. However, certain cases stand out, such as environmental KPIs in planning contexts, which decreased from 10 to 1 KPI (a reduction of 90%). Social and economic KPIs in benchmarking contexts experienced a less dramatic yet still significant reduction (from 11 to 7, about 36%) or social KPIs in monitoring contexts (from 56 to 34, nearly 39%).

Targets

117 Unificated KPIs

The **majority** of KPIs are **aimed at the REC or the REC manager** (about 32%), and policymakers (around 30%), followed by stakeholders (almost 25%). Only 13% of the aggregated KPIs target community members.
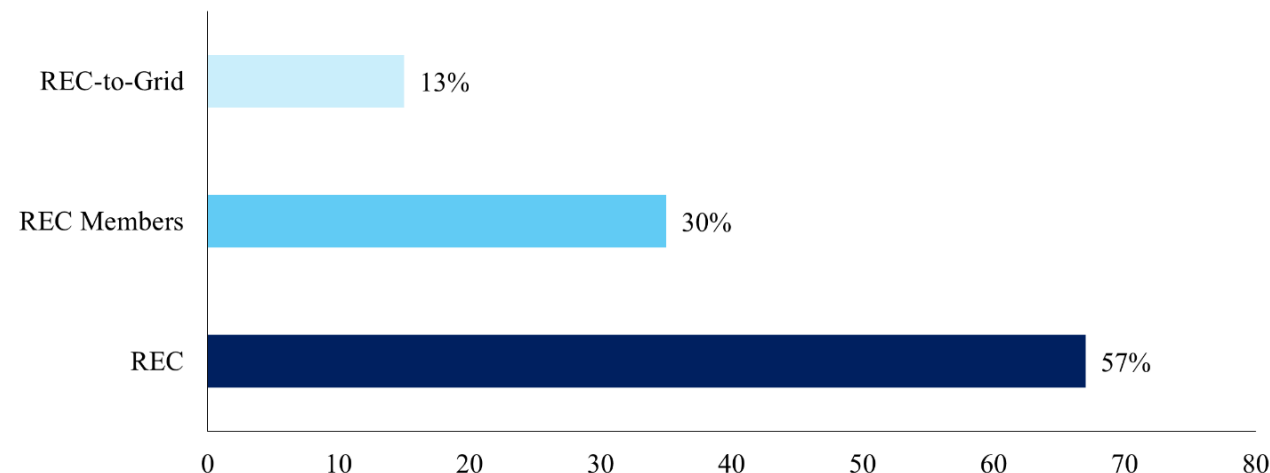
The **"REC" control volume is the most commonly used**, applied to about 57% of the aggregated KPIs. Around 30% of the KPIs are limited to the "REC Members" control volume, and only 13% focus on the "REC-to-Grid" control volume, which pertains to energy flows between the REC and the electrical grid. This shows that **most indicators** used to analyze REC projects generally **require relatively extensive data knowledge**.

Control Volumes

MCA ANALYSIS

Top 10 Energy KPIs based on the obtained MCA score (where UC is the Usages Coverage, TC is the Targets Coverage and F is the frequency, namely the number of articles in which the KPI was defined through mathematical formulations).

KPI	Formula	Definition	UC	TC	F	MCA Score
Electrical Self - Production Rate (ESP)	$ESP = \dfrac{E_{el,prod}}{D}$	Ratio between the total amount of electrical energy produced on the site and the electricity demand (%). $E_{el,prod}$ is the electrical energy produced by RES within the REC, D is the electrical energy demand of the REC.	1.00	0.75	0.50	2.25
Total Energy Used (TEU)	$TEU = \sum_{t=1}^{T}(E_{fg,t} + E_{prod,t})$	Energy supply from local resources inside the community and distribution network-based supply from outside (kWh). $E_{fg,t}$ is the electrical energy taken from the grid at the timestep t, E_{prod} is the electrical energy produced with RES within the REC at the timestep t.	1.00	0.75	0.5	2.25
Self - Consumption Rate (SCR)	$SCR = \dfrac{E_{el,self-cons}}{E_{el,prod}}$	Ratio between the electrical energy self-consumed ($E_{el,self-cons}$) and the electrical energy produced within the REC (%).	0.75	0.50	0.75	2.00
Self - Sufficiency Rate (SSR)	$SSR = \dfrac{E_{el,self-cons}}{D}$	Ratio between the electrical energy self-consumed ($E_{el,self-cons}$) and the electrical energy demand within the REC (%).	0.75	0.50	0.75	2.00
Local Storage Capacities (LSC)	$LSC = \sum_{i=1}^{N} Storage\ Size_i$	Total locally installed storage (kWh or/and kW) capacities inside the community. N is the number of energy storages within the REC.	0.75	1.00	0.25	2.00
Collective Self - Consumption (CSC)	$CSC = \sum_{t=1}^{T}\sum_{n=1}^{N} \min(D_{n,t}, E_{prod,n,t})$	Minimum between the REC demand and production. N is the number of REC members, T is the time window, and $E_{prod,n,t}$ is the energy produced by the n-th member within the REC (kWh) at the timestep t. $D_{n,t}$ is the electrical energy demand by the n-th member within the REC (kWh) at the timestep t.	0.75	1.00	0.25	2.00
Integration Coefficient (IC)	$IC = \dfrac{E_{miss} + E_{excess} + E_{loss}}{D}$	Evaluates how efficiently a REC can integrate variable RES. E_{miss} is the electrical energy which is not covered by electrical production within the REC, E_{excess} is the surplus energy produced within the REC compared to the electricity demand, E_{loss} is the electrical energy wasted due to systems' losses (%).	0.50	1.00	0.25	1.75
Frequency Standard Deviation (F_{std})	$F_{std} = \sqrt{\dfrac{\sum_{i=1}^{n}(f_i - f)^2}{n}}$	Quantifies the dispersion of frequency around the target value of 50/60 Hz. A lower value of the standard deviation of the frequency indicates a stable and reliable REC. f is the frequency of the part of the electrical grid within the REC (Hz).	0.50	1.00	0.25	1.75
End-REC Members Automation (RMA)	$RMA = \dfrac{N_{remotely\ controll.loads}}{N_{REC\ loads}}$	Percentage of REC loads (including residential) remotely controllable through an API (%).	0.50	1.00	0.25	1.75
New Energy Related Services (ERS)	$ERS = N_{services\ REC-members}$	Number of energy services provided by REC to the stakeholders and end-REC Members (market-related, remote monitoring, etc).	0.75	0.75	0.25	1.75

Top 10 Economic KPIs based on the obtained MCA score (where UC is the Usages Coverage, TC is the Targets Coverage and F is the frequency, namely the number of articles in which the KPI was defined through mathematical formulations).

KPI	Formula	Definition	UC	TC	F	MCA Score
Annual Energy Cashflow (AEC)	$AEC = \sum_i Exp_i - \sum_j Inc_j$	Difference between the total yearly incomes and the expenses incurred for energy consumption and production (€/year).	0.75	0.75	1.00	2.50
Businesses Creation (BC)	$BC = N_{bus,REC}$	Number of new businesses created within the REC design and deployment.	0.75	1.00	0.25	2.00
Capital Expenditure (CAPEX)	$CAPEX = \sum_i C_{i,0}$	Initial costs incurred for the development, construction, and installation of infrastructure and equipment necessary to generate, store, and distribute renewable energy (€).	0.50	0.75	0.25	1.50
Economic Sustainability Factor (EF)	$EF = \dfrac{\sum_{i=1}^{N} \frac{Inc_i}{N}}{\sum_{i=1}^{N} \frac{C_i}{N}}$	Comparison between project incomes and the system costs (%)., where N is the number of years.	0.50	1.00	0.25	1.75
Share of Individual Savings (SIS)	$SIS = \dfrac{\sum_{i=1}^{N}(P_i - P_i^*)}{\sum_{i=1}^{N} P_i}$	Percentage of savings made by an individual prosumer or consumer for trading energy in the REC as compared to trading without the REC (%), where P_i and P_i^* are the net costs for trading electricity without and with the REC, for the i-th user.	0.50	1.00	0.25	1.75
Community Share of Market Savings (CSMS)	$CSMS = \dfrac{\sum_{i=1}^{N}(P_{DSO,i} - P_{DSO,i}^*)}{\sum_{i=1}^{N} P_{DSO,i}}$	Sum of the shares of individual savings made by each local agent (DSOs) for trading energy within the REC ($P_{DSO,i}$) as compared to trading without the REC ($P_{DSO,i}^*$) (%).	0.50	1.00	0.25	1.75
Economic Incentives (EI)	$EI = N_{economic\ tools,REC}$	Yearly number of economic tools generated by the REC such as green or white certificates to decarbonise energy.	0.50	1.00	0.25	1.75
Business Diversity (BD)	$BD = N_{bus\ type,REC}$	Number of business types involved in the REC. It ranges between 1 and 5 based on the following typology of business within the REC: public, industrials, consulting, academics, SME, large enterprises.	0.50	1.00	0.25	1.75
Energy Bills Reduction (EBR)	$EBR = 1 - \dfrac{\sum_{i=1}^{N} C_{bill,ex-REC,i}}{\sum_{i=1}^{N} C_{bill,REC,i}}$	Ratio between the energy bills before the development of the REC and energy bills after the creation of the REC. N is the total number of users within the REC (%).	0.25	1.00	0.25	1.50
Net Present Values (NPV)	$NPV = -CAPEX + \sum_{i=0}^{N} \dfrac{CF_i}{(1-a)^i}$	Represents the difference between the present value of cash inflows and the present value of cash outflows over the project's lifetime (€). a is the annual discount rate and i is the year. N corresponds to the duration of the observed timeframe.	0.25	0.75	0.25	1.25

Top 10 Environmental KPIs based on the obtained MCA score (where UC is the Usages Coverage, TC is the Targets Coverage and F is the frequency, namely the number of articles in which the KPI was defined through mathematical formulations).

KPI	Formula	Definition	UC	TC	F	MCA Score
Environmental Impact (ENVI)	$ENVI = \dfrac{X_{poll,REC}}{X_{poll,ex-REC}}$	Environmental Impact in terms of tons per year of avoided X-specific pollutant (%).	1.00	0.75	1.00	2.75
Low carbon Public Transportation Vehicles deployment rate (LPTV)	$LPTV = \dfrac{N_{LPTV}}{N_{REC\ public\ vehicles}}$	Assessment of the deployment rate of low carbon technologies for transport (%), where $N_{REC\ public\ vehicles}$ is the sum of total public vehicles, and N_{LPTV} is the number of low carbon vehicles within the REC.	0.50	1.00	0.25	1.75
Noise Pollution Reduction (NPR)	$NPR = \dfrac{db_{REC}}{dB_{ex-REC}}$	Assesses the percentage reduction of dB due to REC actions (%), where dB is the mean noise pollution registered within the REC.	0.50	0.75	0.25	1.50
Biodiversity Impact (BI)	$BI = \sum_{i=1}^{I} S_{REC,i}$	Gathers information regarding possible disruption to biodiversity of local species as well as danger to certain animals and plants. Assessed by the number of animal species threatened by REC actions, where $S_{REC,i}$ refers to the i-th specie.	0.50	0.75	0.25	1.50
Use of Land (UoL)	$UoL = \sum_{i=1}^{I} A_{no\ more\ avail,i}$	Surface of area no more available for agriculture or biodiversity because of REC actions (m2). $A_{no\ more\ avail,i}$ refers to the i-th surface within the REC no more available for agriculture or biodiversity.	0.50	0.75	0.25	1.50
Rare Earth Element Consumption (REEC)	$REEC = \sum_{i=1}^{R} kg_{rare\ earth,i}$	Assess the resource consumption for the deployment of REC of rare earth material (kg), where $kg_{rare\ earth,i}$ refers to the i.th rare earth element used for the deployment of the REC.	0.50	0.75	0.25	1.50
GHG Emissions (GHGE)	$GHGE = \sum_{i=1}^{I} (CO2_{eq,prod.i} + CO2_{eq,oper,i} + CO2_{eq,trans})$	GHG emissions (carbon footprint) in the community (kg of CO2-eq.) as the sum of the CO2 emission from production, operation and transportation of energy within the REC.	0.25	0.75	0.25	1.25

Top 10 Social KPIs based on the obtained MCA score (where UC is the Usages Coverage, TC is the Targets Coverage and F is the frequency, namely the number of articles in which the KPI was defined through mathematical formulations).

KPI	Formula	Definition	UC	TC	F	MCA Score
Local Representation (LR)	$LR = \dfrac{N_{rep,REC}}{N_{REC}}$	Assess the representativeness of the people constituting the local governance team (%). $N_{rep,REC}$ is the number of REC members feeling representative by the governance team, while N_{REC} is the total number of REC members.	0.50	1.00	0.25	1.75
Social Energy Empowerment (SEE)	$SEE = \dfrac{N_{resp,REC}}{N_{REC}}$	Percentage of the population feeling responsible ($N_{resp,REC}$) for their own energy consumption (%).	0.50	1.00	0.25	1.75
Social Business Development (SBD)	$SBD = B_{EP} + B_{FP}$	Number of social businesses including consideration for energy poverty (B_{EP}) and fuel poverty (B_{FP}).	0.50	1.00	0.25	1.75
Citizens' Satisfaction (CS)	$CS = \dfrac{N_{satisf,REC}}{N_{REC}}$	Through surveys, this KPI indicates the degree of satisfaction of the population due to RECs measures. Assessed in the percentage of the population surveyed that is satisfied ($N_{satisf,REC}$) (%).	0.50	1.00	0.25	1.75
Local Employment (LE)	$LE = N_{jobs,REC}$	Number of newly created job by REC stakeholders ($N_{jobs,REC}$), that are locally developed.	0.50	1.00	0.25	1.75
Consumer Financial Benefits (CFB)	$CFB = \dfrac{N_{bill\ red,REC}}{N_{REC}}$	Percentage of REC members with a bill reduction ($N_{bill\ red,REC}$) in cost per kWh (%).	0.50	1.00	0.25	1.75
Stakeholders Diversity (SD)	$SD = N_{s\ tyoe,REC}$	Diversity of types of stakeholders ($N_{s\ type,REC}$) involved in the REC (large private companies, SMEs, public organizations, etc.), from 1 to 4.	0.50	1.00	0.25	1.75
Local Innovations (LI)	$LI = N_{inovv} + N_{patents}$	Number of innovations (N_{innov}) such as products, services; and patents ($N_{patents}$) from local community and stakeholders.	0.50	1.00	0.25	1.75
Education Programs Development (EPD)	$EPD = N_{ed\ programs,REC}$	Number of new energy-related local educational programs ($N_{ed\ programs,REC}$) created within the REC deployment project.	0.50	1.00	0.25	1.75
Event Dynamism (EVD)	$EVD = N_{events,REC}$	Number of project forums, workshops, seminars ($N_{events,REC}$) within the REC.	0.50	1.00	0.25	1.75

KPIs REFERENCE LIST

This comprehensive set is designed to assess various aspects of REC, offering a reference set of metrics that are categorized by sector, scope of use, target, and control volume. The KPIs Reference List is intended to support different target groups through analysis across all phases of REC projects while maintaining consistency in data requirements and mathematical definitions for various applications.

KPI	Sector Domain	Formula	Definition	Usage	Target	Control Volume
Shared Energy (SE)	Energy	$SE = \min\left(E_{fg}, E_{tg}\right)$	Minimum value, in every time step, between the energy withdrawn from the electrical grind and the electrical energy injected to the grid (kWh).	Planning, Monitoring	REC, Policymakers, Stakeholders	REC-To-Grid
Self – Consumption Rate (SCR)	Energy	$SCR = \dfrac{\sum_{t=1}^{T}(E_{el,self-cons,t} + SE_t)}{\sum_{t=1}^{T} E_{el,prod,t}}$	Ratio between the electrical energy self-consumed plus the shared energy and the electrical energy produced within the REC. $E_{el,self-cons,t}$, SE_t, and $E_{el,prod,t}$ are respectively the self-consumed, the shared energy, and the electrical energy produced within the REC at the timestep t. T is the temporal extension in which the KPI is evaluated.	Planning, Monitoring, Benchmarking	REC, Policymakers, Stakeholders	REC
Self – Sufficiency Rate (SSR)	Energy	$SSR = \dfrac{\sum_{t=1}^{T}(E_{el,self-cons,t} + SE_t)}{\sum_{t=1}^{T} D_t}$	Ratio between the electrical energy self-consumed plus the shared energy and the electrical energy demand within the REC (%). T is the temporal extension in which the KPI is evaluated.	Planning, Monitoring, Benchmarking	REC, Policymakers, Stakeholders	REC
Electrical Self – Production Rate (ESP)	Energy	$ESP = \dfrac{\sum_{t=1}^{T} E_{el,prod,t}}{\sum_{t=1}^{T} D_t}$	See Table 5. T has been added as the temporal extension in which the KPI is evaluated.	Planning, Monitoring, Benchmarking	REC, Policymakers, Stakeholders	REC Members
Grid Energy Interaction Factor (GEIF)	Energy	$GEIF = \dfrac{\sum_{t=1}^{T}\left(E_{el,fg,t} + E_{el,tg,t}\right)}{\sum_{t=1}^{T} D_t}$	Ratio between the energy taken from the grid, the energy injected to the grid, and the electricity demand of the REC (%). T is the temporal extension in which the KPI is evaluated.	Operation, Monitoring	REC, Policymakers	REC
Synchronization Coefficient (SYC)	Energy	$SYC = \dfrac{\sum_{t=1}^{T} E_{el,fg}^{*}}{\sum_{t=1}^{T} E_{el,fg}}$	Ratio between the electrical energy withdrawn from the grid when electrical energy is also produced by the REC ($E_{el,fg}^{*}$), and the overall electrical energy withdrawn from the grid ($E_{el,fg}$) (%). T is the temporal extension in which the KPI is evaluated.	Planning, Operation, Monitoring	REC, REC Members, Stakeholders	REC
Energy Storage Opportunity (ESO)	Energy	$ESO = \sum_{t=1}^{\tau} \max\left(0, \min\left(E_{REC\,sur,t}, E_{REC\,def,t}\right) - E_{REC\,storage,t}\right)$	Quantifies the need for energy storage systems within the REC comparing the electrical energy surplus at the timestep t ($E_{REC\,sur,t}$), the electrical energy deficit ($E_{REC\,def,t}$) and the electrical energy charged or discharged at the timestep t by batteries within the REC ($E_{REC\,storage,t}$) (kWh).	Operation	REC, Stakeholders	REC
Flexibility Activated (FA)	Energy	$FA = \sum_{i=1}^{T} E_{flex,t}$	Annual energy used within the REC for flexibility purposes ($E_{flex,t}$) (kWh). T has been added as the temporal extension in which the KPI is evaluated.	Monitoring	REC, Policymakers	REC-To-Grid

Although in the previous steps, the KPIs have already been categorized by Usage and Target according to how they were used in the articles previously analyzed, here the authors propose the Targets and Usages they consider most appropriate for each KPI based on their knowledge of the REC field. In addition, the authors in this list propose some new KPIs or modifications of existing ones previously identified to fill gaps in the literature and improve the effectiveness of the indicators.

In the economic category, four of the KPIs were selected from the MCA results to ensure comprehensive coverage of the Usages and Targets. KPIs such as Annual Energy Cashflow, Capital Expenditure, and Economic Sustainability Factor were not selected because they are necessary to calculate broader KPIs like NPV and IRR, which provide more significant insights into the project's feasibility, despite lower MCA scores. Indicators like Business Creation and Business Diversity were excluded in favor of KPIs that offer deeper insights into the impact of local market implementation within the REC.

KPI	Sector Domain	Formula	Definition	Usage	Target	Control Volume
Payback Time (PBT)	Economic	$PBT = \dfrac{C_0}{Inc_y - Exp_y}$	Refers to the period required for the savings and revenues generated from the REC project to equal the initial investment cost (y) Incomes and expenses must be actualized using the discount rate.	Planning	REC, REC Members, Stakeholders	REC
Energy Bills Reduction (EBR)	Economic	$EBR = 1 - \dfrac{\sum_{t=1}^{T} C_{bill,ex-REC,t}}{\sum_{t=1}^{T} C_{bill,REC,t}}$	See Economic KPIs Table. T has been added as the temporal extension in which the KPI is evaluated.	Monitoring, Benchmarking	REC Members	REC Members
Levelized Cost of Energy Consumed (LCOEC)	Economic	$LCOEC = \dfrac{\sum_{n=1}^{N} \dfrac{I_n + M_n}{(1+a)^n}}{\sum_{n=1}^{N} \dfrac{E_n}{(1+a)^n}}$	Refers to the average cost per unit of energy consumed by the community over a time window (N) of the energy system. This metric considers all relevant costs, including capital expenditure (I), operation and maintenance (M), and financing, spread out over the total energy consumed by the community (E_n) (€/kWh).	Planning, Benchmarking	REC, Stakeholders	REC
Share of Individual Savings (SIS)	Economic	$SIS = \dfrac{\sum_{i=1}^{N}(P_i - P_i^*)}{\sum_{i=1}^{N} P_i}$	See Economic KPIs Table.	Operation, Monitoring	REC, REC Members	REC Members
Community Share of Market Savings (CSMS)	Economic	$CSMS = \dfrac{\sum_{i=1}^{N}(P_{DSO,i} - P_{DSO,i}^*)}{\sum_{i=1}^{N} P_{DSO,i}}$	See Economic KPIs Table.	Operation, Monitoring	REC, REC Members	REC Members
Revenues from Flexibility (RF)	Economic	$R_{flex} = \sum_{t=1}^{T} p_{flex,t} * E_{flex,t}$	Represents the revenues generated through flexibility services (€). $p_{flex,t}$ is a unit cost expressed in €/kWh_{flex} and $E_{flex,t}$ is the energy provided at the timestep t. $p_{flex,t}$ is comprehensive both of flexibility availability and activation.	Monitoring	REC, REC Members, Policymakers	REC-To-Grid
Internal Rate of Return (IRR)	Economic	$0 = NPV = -CAPEX + \sum_{i=1}^{N} \dfrac{CF_i}{(1-IRR)^n}$	It represents the discount rate at which the net present value (NPV) of all cash flows (both inflows and outflows) from the investment equals zero.	Planning	REC; REC Members, Stakeholders	REC

5) KPIs Reference List – Environmental KPIs

For the environmental domain, the authors selected 4 KPIs that capture the overall environmental impact of the REC, including land use (Use of Land), pollutant emissions (GHG Emissions and Environmental Impact), and emission reductions from electric vehicle integration (Low Carbon Public Transportation Vehicles Deployment Rate). KPIs such as Noise Pollution Reduction, Rare Earth Element Consumption, and Biodiversity Impact were excluded because they provide more specialized information and are less relevant for general environmental assessments of RECs.

KPI	Sector Domain	Formula	Definition	Usage	Target	Control Volume
Environmental Impact (ENVI)	Environmental	$ENVI = \dfrac{\sum_{t=1}^{T} X_{poll,REC,t}}{\sum_{t=1}^{T} X_{poll,ex-REC,t}}$	See Environmental KPIs Table. T has been added as the temporal extension in which the KPI is evaluated.	Planning, Monitoring, Benchmarking	REC, Policymakers	REC
Low carbon Public Transportation Vehicles deployment rate (LPTV)	Environmental	$LPTV = \dfrac{N_{LPTV}}{N_{REC\ public\ vehicles}}$	See Environmental KPIs Table.	Monitoring, Benchmarking	REC, REC Members, Policymakers	REC
Use of Land (UoL)	Environmental	$UoL = \sum_{i=1}^{I} A_{no\ more\ avail,i}$	See Environmental KPIs Table.	Planning, Monitoring	REC, Policymakers	REC
GHG Emissions (GHGE)	Environmental	$GHGE = \sum_{i=1}^{T}\left(CO2_{eq,prod,t} + CO2_{eq,oper,t} + CO2_{eq,trans,t}\right)$	See Environmental KPIs Table. T has been added as the temporal extension in which the KPI is evaluated.	Operation, Monitoring	REC, Policymakers	REC

The selected social KPIs are designed to quantify the REC's impact on the local population, the awareness of their role, and the benefits of the REC (such as Energy Poverty Help, Local Representation, Social Energy Empowerment, and Social Business Development). In contrast to the Social KPIs Table shown as the result of the MCA, the authors also included indicators that address the critical aspect of monitoring and data availability over time, represented by Open Data Access and Local Data Governance.

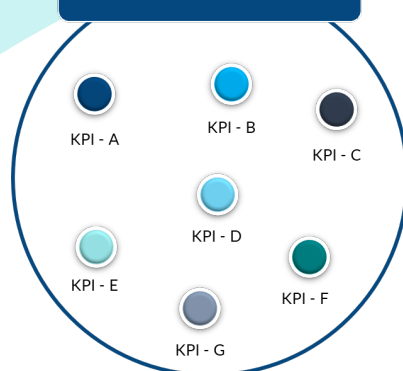| KPI	Sector Domain	Formula	Definition	Usage	Target	Control Volume
Social Energy Empowerment (SEE)	Social	$SEE = \dfrac{N_{resp,REC}}{N_{REC}}$	See Social KPIs Table.	Monitoring	REC Members	REC
Social Business Development (SBD)	Social	$SBD = B_{EP} + B_{FP}$	See Social KPIs Table.	Monitoring	REC, REC Members	REC
Energy Poverty Help (EPH)	Social	$EPH = \dfrac{REC_{Inc}}{MUC * Bp_{grid}}$	Represents the ration between incomes of the REC (REC_{Inc}) and the Mean User Consumption (MUC) multiplied by the buying price of electrical energy from the grid (BP_{grid}). It assesses how many REC members in energy poverty could be helped by the REC.	Monitoring, Benchmarking	REC, REC Members	REC
Open Data Access (ODA)	Social	$ODA = \dfrac{REC_{open\,data}}{REC_{data}}$	Percentage of anonymised or aggregated monitored data accessible to the public through an API (%).	Monitoring, Benchmarking	REC, REC Members, Policymakers	REC
Local Data Governance (LDG)	Social	$LDG = Yes/No$	Indicates if a committee of citizens and stakeholders (industrial, academics, social scientists, etc) has been established to work on different aspects of local data (sharing agreement, monitoring agreement, GDPR support, transparency, etc).	Planning	REC, REC Members, Stakeholders	REC
Local Representation (LR)	Social	$LR = \dfrac{N_{rep,REC}}{N_{REC}}$	See Table 8.	Monitoring, Benchmarking	REC, REC Members	REC

CONCLUSIONS

This study provides a comprehensive framework for assessing Renewable Energy Communities (RECs) by **reviewing and categorizing 316 Key Performance Indicators (KPIs)** across energy, economics, social impact, and environmental sustainability. After an extensive analysis, a **refined set of 117 KPIs** was developed, culminating in a **final list of 25 essential KPIs.** These indicators are designed to guide REC planning, operations, and benchmarking, offering insights for policymakers, stakeholders, and community members.

25 KPIs Reference List

KPI	Sector Domain	Formula	Usage	Target	Control Volume
Shared Energy (SE)	Energy	$SE = \min(E_{fg}, E_{tg})$	Planning, Monitoring	REC, Policymakers, Stakeholders	REC-To-Grid
Payback Time (PBT)	Economic	$PBT = \dfrac{C_0}{Inc_y - Exp_y}$	Planning	REC, REC Members, Stakeholders	REC
GHG Emissions (GHGE)	Environmental	$GHGE = \sum_{i=1}^{T}(CO2_{eq,prod.t} + CO2_{eq,oper,t} + CO2_{eq,trans,t})$	Operation, Monitoring	REC, Policymakers	REC
Social Energy Empowerment (SEE)	Social	$SEE = \dfrac{N_{resp,REC}}{N_{REC}}$	Monitoring	REC Members	REC

MCA Results

Energy KPIs

Economic KPIs

Environmental KPIs

Social KPIs

117 Unificated KPIs

KPI - A, KPI - B, KPI - C, KPI - D, KPI - E, KPI - F, KPI - G

Papers Exploration

251 – Scopus & Web Of Science
- Published since 2010;
- Journal papers.

Papers Screening

151 – Scopus & Web Of Science
- Full-text available paper [1];
- Check on research domain.

Papers Eligibility

53 – Scopus & Web Of Science
- Papers that make use of KPIs in the context of the RECs [2].

[1] Availability is based on the Polytechnic of Turin and ENEA accessibility to research works.
[2] Only paper that explicitly define and use KPIs are taken in account.

THANKS FOR YOUR ATTENTION

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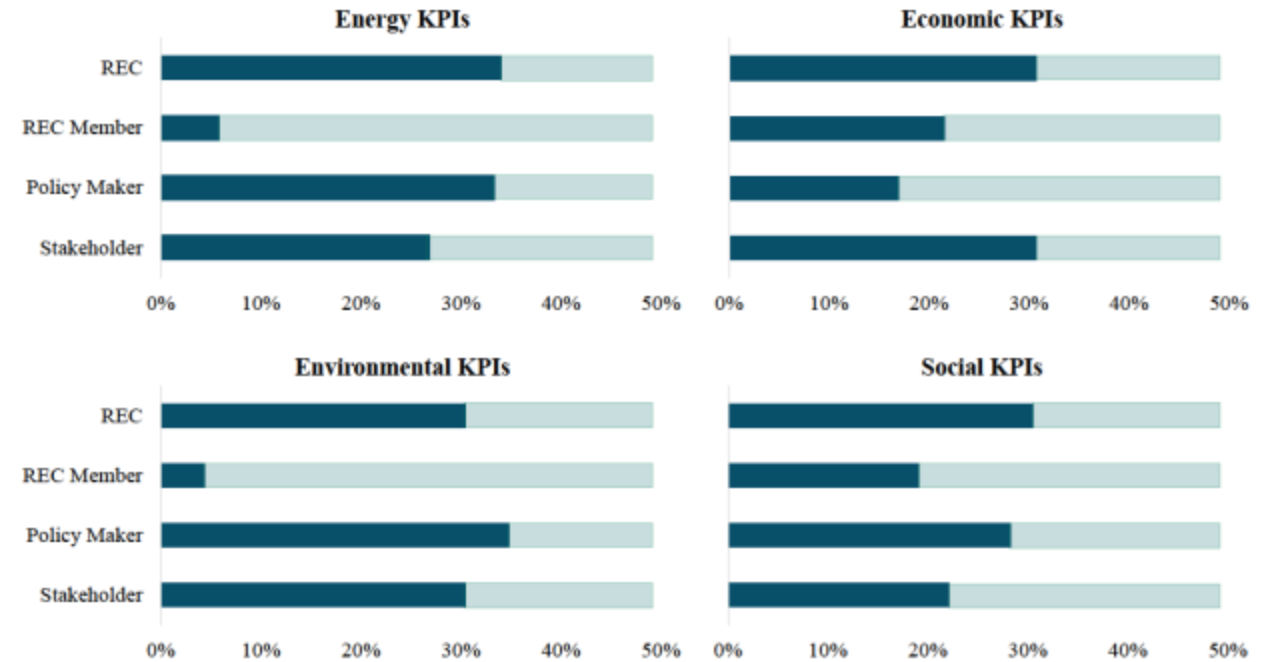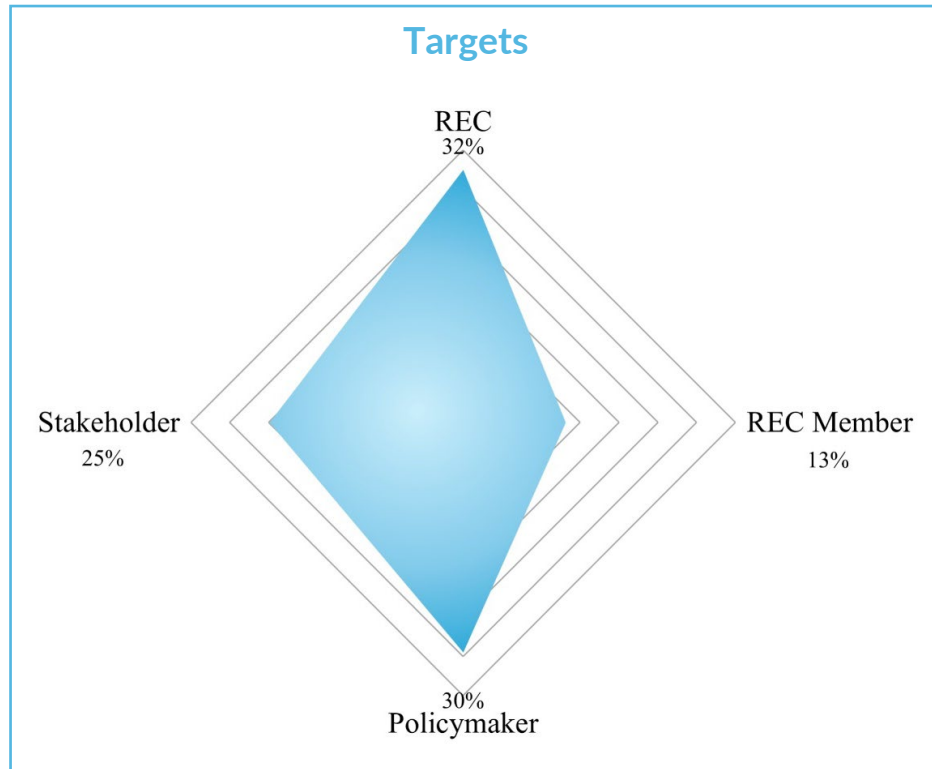Recent Top Papers (60 days)   As of: 14 Nov 2024 - 13 Jan 2025

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- **Energy KPIs** are primarily directed at the REC or REC manager (34%) and policymakers (33%), with a smaller focus on stakeholders (almost 27%), and very little interest for REC members (6%);

- **Environmental KPIs** show a similar trend, with a minimal focus on REC members (4%), and balanced distribution among other targets (30-35%);

- **Social KPIs**, however, show a more balanced distribution across REC (30%), policymakers (28%), stakeholders (22%), and REC members (19%);

- **Economic KPIs** are mainly directed to the REC and stakeholders (31% each), with less focus on REC members (22%) and policymakers (17%).
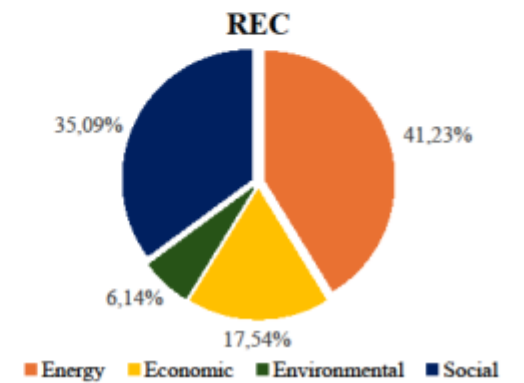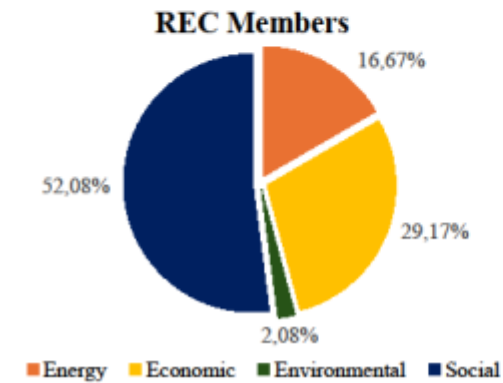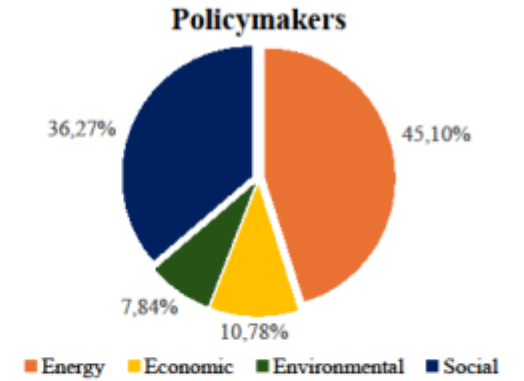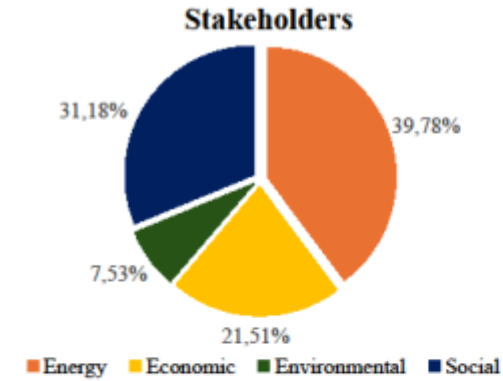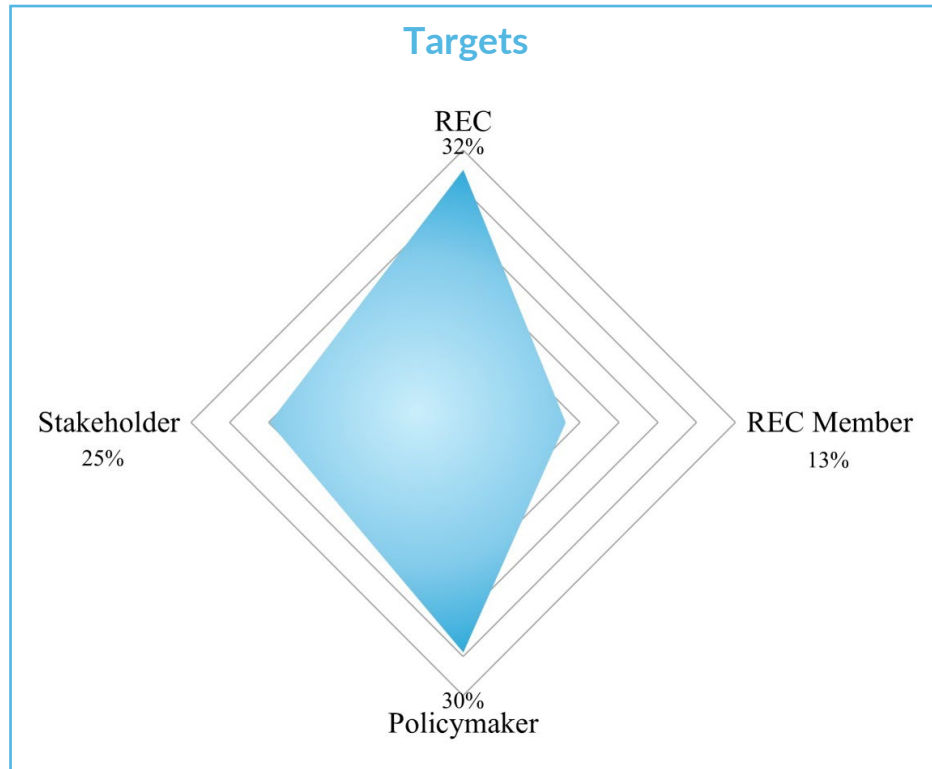
Social KPIs dominate those addressed to REC members (52%). Energy and social KPIs are more frequently directed toward the REC, policymakers, and stakeholders, while environmental and economic KPIs, on the other hand, are less prominent, except when economic KPIs are directed at stakeholders or REC members.