Supporting a Sustainable Multi-Energy Planning: The Case Study of Sulcis Iglesiente Province in Italy

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Abstract

In the energy transition context, the design of integrated multi-energy systems is key for reaching ambitious sustainability objectives. Due to the intermittent nature of the renewable energy sources, introducing technologies for storing and transforming energy in different carriers (e.g., electricity, gas, heat) is, in fact, a strategic solution for fully exploiting the renewable power generation, increasing the flexibility of the system, and contributing to the decarbonization. Although the need to rely on multi-energy systems is widely shared, identifying their optimal design requires the use of complex modelling tools able to characterize the territory, simulate the system dynamics, and evaluate the solutions with respect to different sustainability objectives. To support the decarbonization decision-making process, in this work we develop a three-step modelling chain for planning optimal multi-energy systems at the local scale. More precisely, we first perform a territory characterization by estimating, through different methodologies, input data of renewable resource availability, territory exploitation potential, and energy demand of electricity and heat. Then, we carry out a multi-energy analysis identifying Pareto optimal system designs with respect to two sustainability objectives, namely the Net Present Cost and the CO_2 emissions. Finally, we perform an intersectoral Multi Criteria Analysis-Cost Benefit Analysis (MCA-CBA) for evaluating the solutions obtained in the previous step with respect to a wide range of indicators representing energy, economic, and social acceptance aspects. The CBA approach is adopted for evaluating the financial and economic viability of the investment options, while the assessment of non-monetary impacts is performed through the MCA approach. We apply the modelling chain to the real case study of Sulcis Iglesiente (Sardinia, Italy), a territory characterized by carbon-intensive industries, recently selected for receiving funding from the Just Transition Fund launched by the EU Commission in the context of the Green Deal. Expected results aim to demonstrate the validity of the proposed modelling chain in the identification of the best interventions for supporting the decarbonization and the sustainable development of Sulcis Iglesiente.

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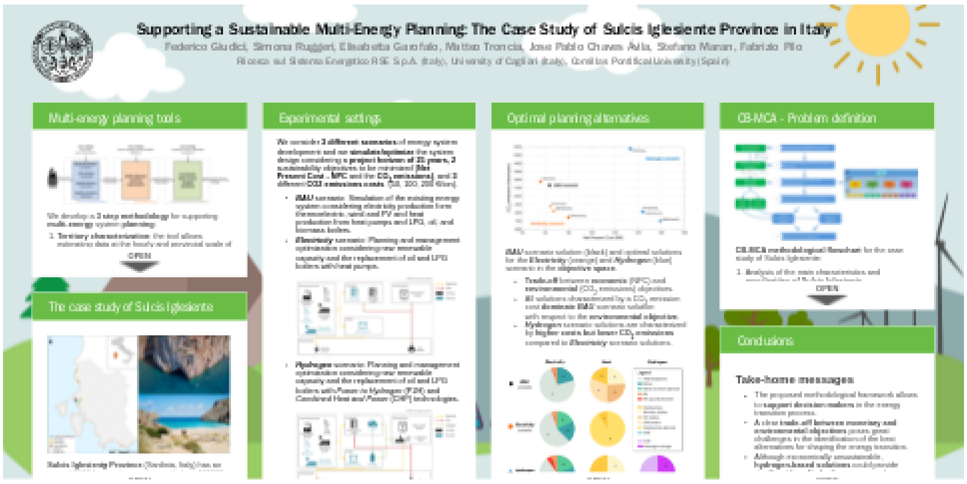

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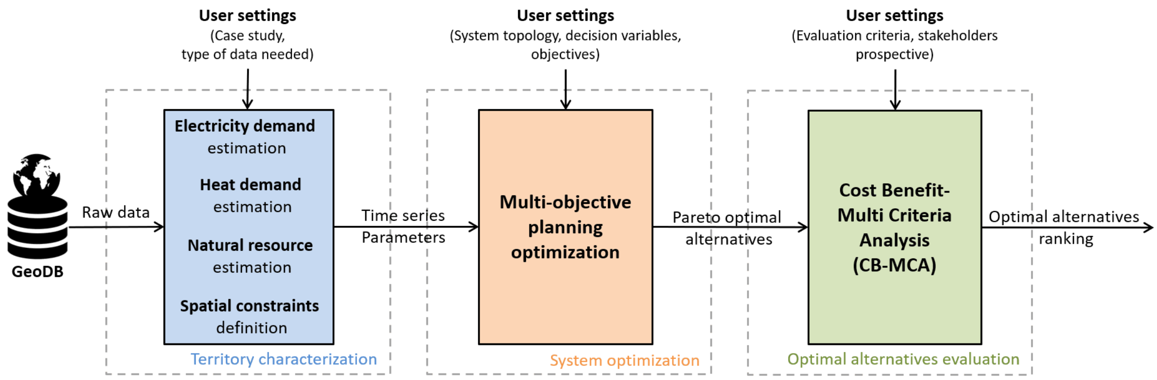
PRESENTED AT:

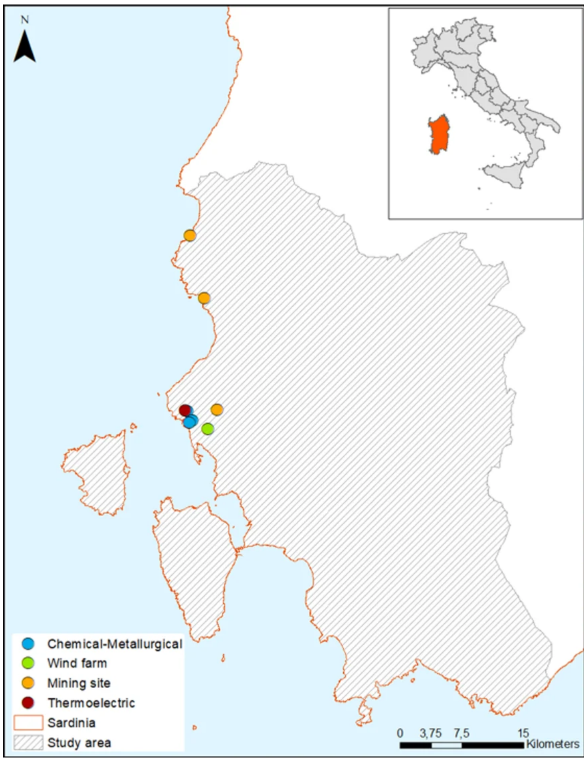
MULTI-ENERGY PLANNING TOOLS



We develop a **3 step methodology** for supporting **multi-energy** system **planning**:

1. **Territory characterization**: the tool allows estimating data at the hourly and provincial scale of renewable resource availability, territory exploitation potential and energy demand of electricity and heat for the entire Italian territory.
2. **System optimization**: the tool performs a system optimization using the Calliope model identifying Pareto optimal planning solutions with respect to monetary and environmental objectives.
3. **CB-MCA**: the tool allows to combine a Cost Benefit analysis with a Multi Criteria analysis for evaluating the Pareto optimal alternatives with respect to a wide range of indicators, considering different stakeholder prospectives and preferences.

THE CASE STUDY OF SULCIS IGLESIENTE



Sulcis Iglesiente Province (Sardinia, Italy) has an area of **2117 km^2** and a population of about **125000 inhabitants**.

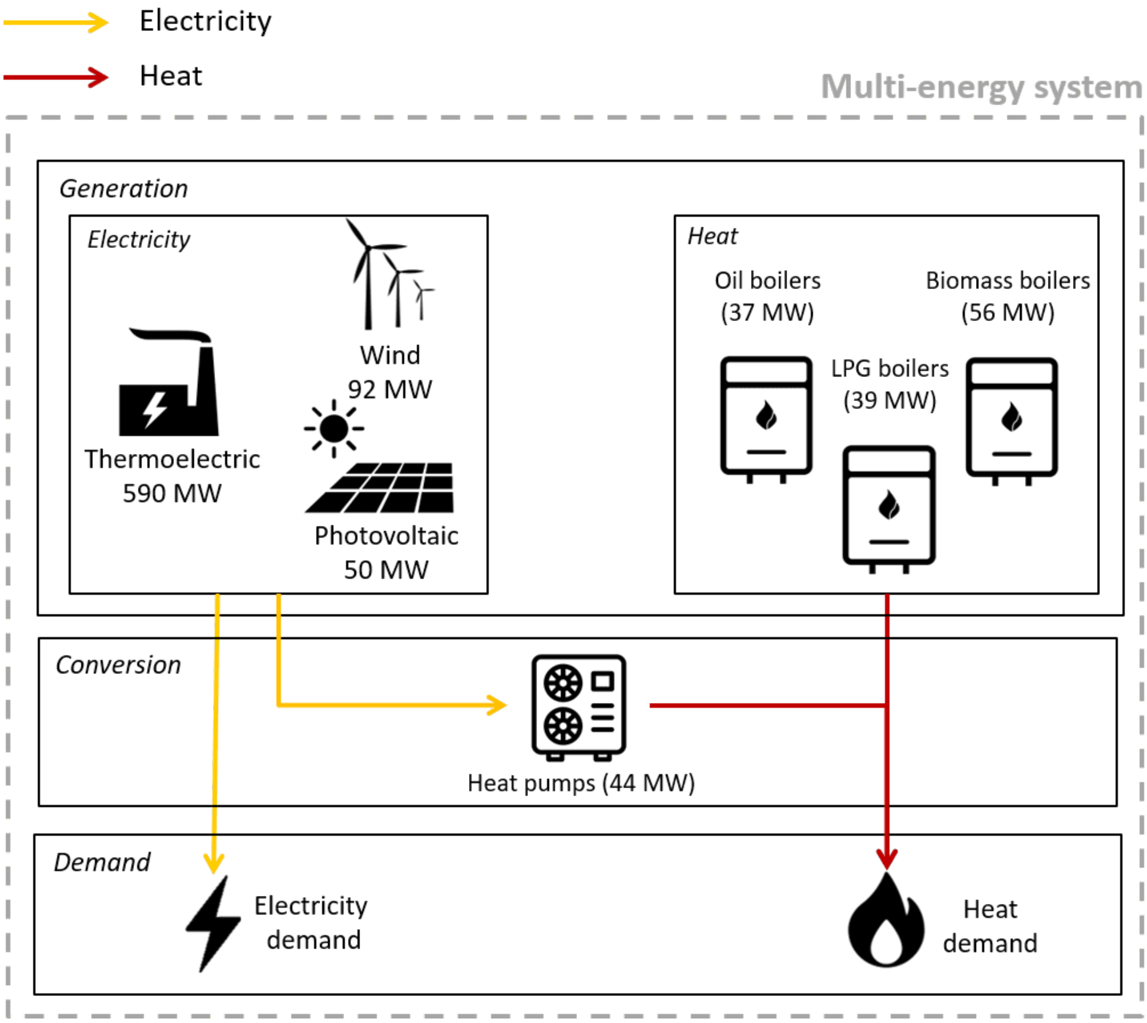
The province is characterized by the presence of several **mining sites** (now disused), which have been constructed between 1800 and 1980.

In 1950, one of the most important European **aluminum-energy-metallurgy chain** has been developed with the construction of a large thermoelectric power plant (590 MW).

From 2018, the **cessation of several industrial activities** have been strongly **impacted on the local economy**.

In 2021, the site has been selected to be **financed by the European Just Transition Fund** for promoting a just and sustainable transition.

Energy System



Electricity generation (1100 GWh/year)

- Thermoelectric (590 MW)
- Wind (92 MW)
- PV (50 MW)

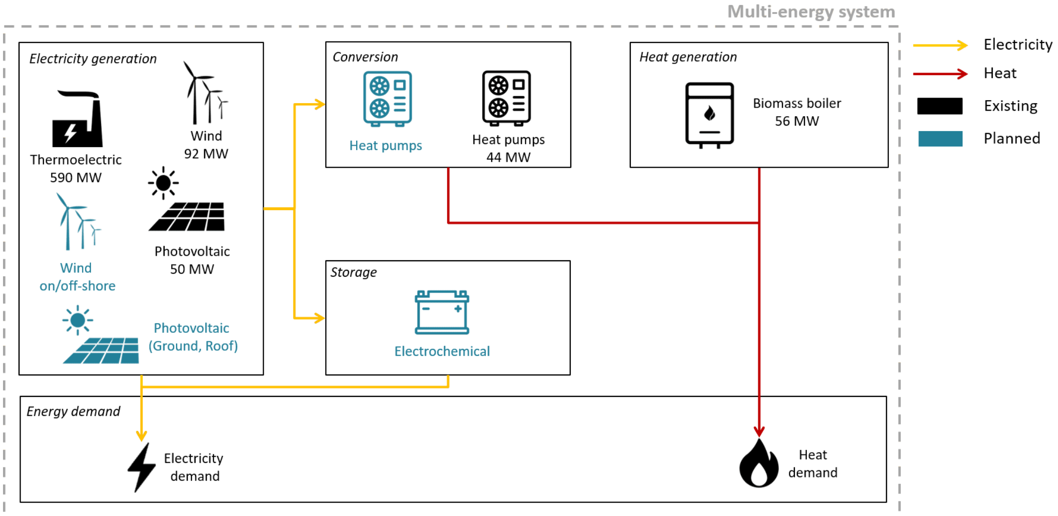
Heat generation (530 GWh/year)

- Oil boilers (37 MW)
- LPG boilers (39 MW)
- Biomass boilers (56 MW)
- Heat pumps (44 MW)

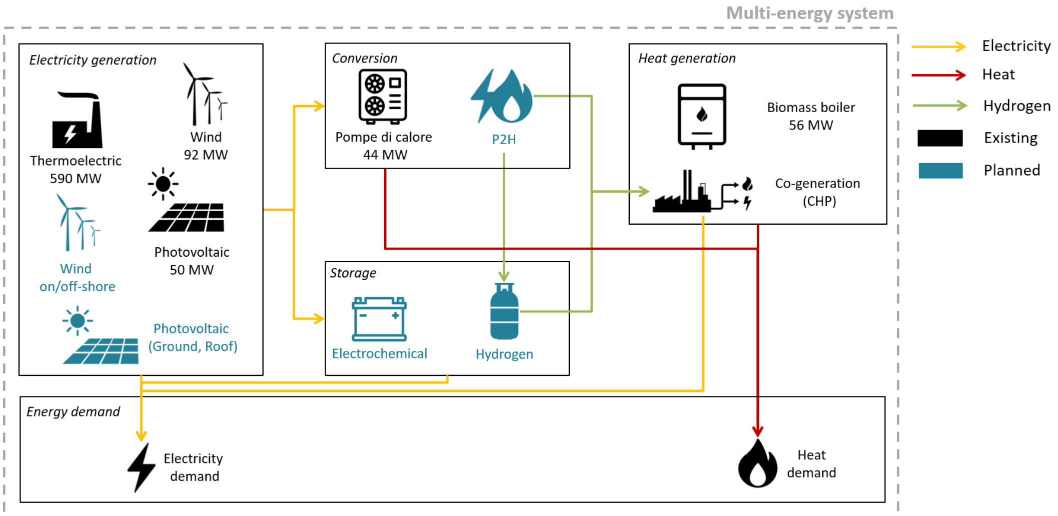
EXPERIMENTAL SETTINGS

We consider **3 different scenarios** of energy system development and we **simulate/optimize** the system design considering a **project horizon of 25 years, 2** sustainability objectives to be minimized (**Net Present Cost - NPC** and the **CO_2 emissions)**, and **3** different **CO2 emissions costs** (50, 100, 200 €/ton).

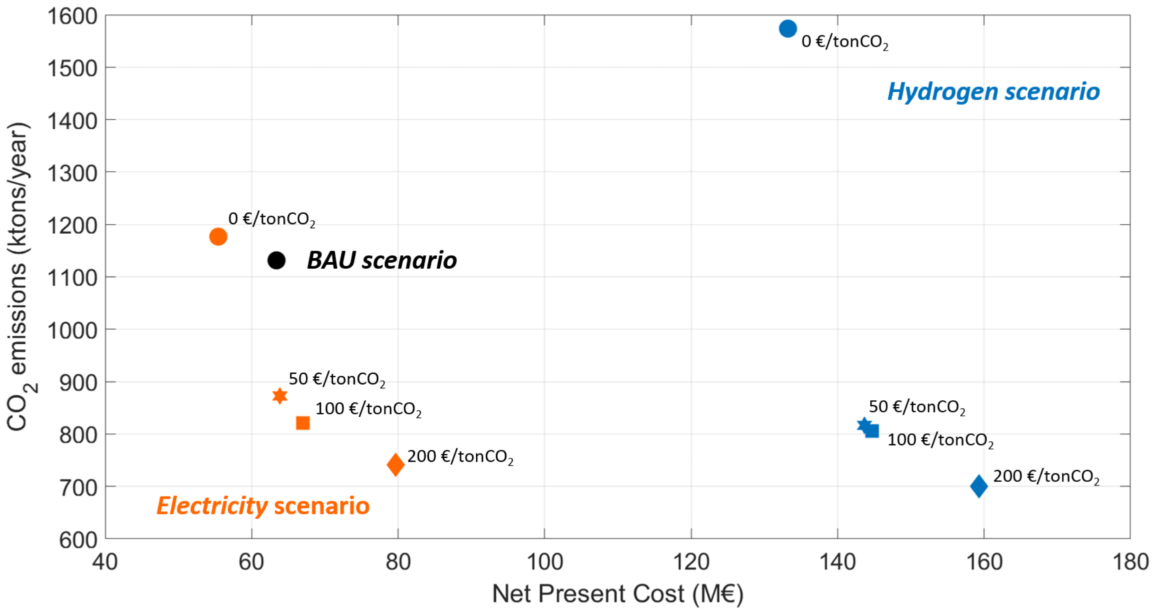
- ***BAU*** scenario: Simulation of the existing energy system considering electricity production form thermoelectric, wind and PV and heat production from heat pumps and LPG, oil, and biomass boilers.
- ***Electricity*** scenario: Planning and management optimization considering new renewable capacity and the replacement of oil and LPG boilers with heat pumps.



- ***Hydrogen*** scenario: Planning and management optimization considering new renewable capacity and the replacement of oil and LPG boilers with *Power to Hydrogen* (P2H) and *Combined Heat and Power* (CHP) technologies.

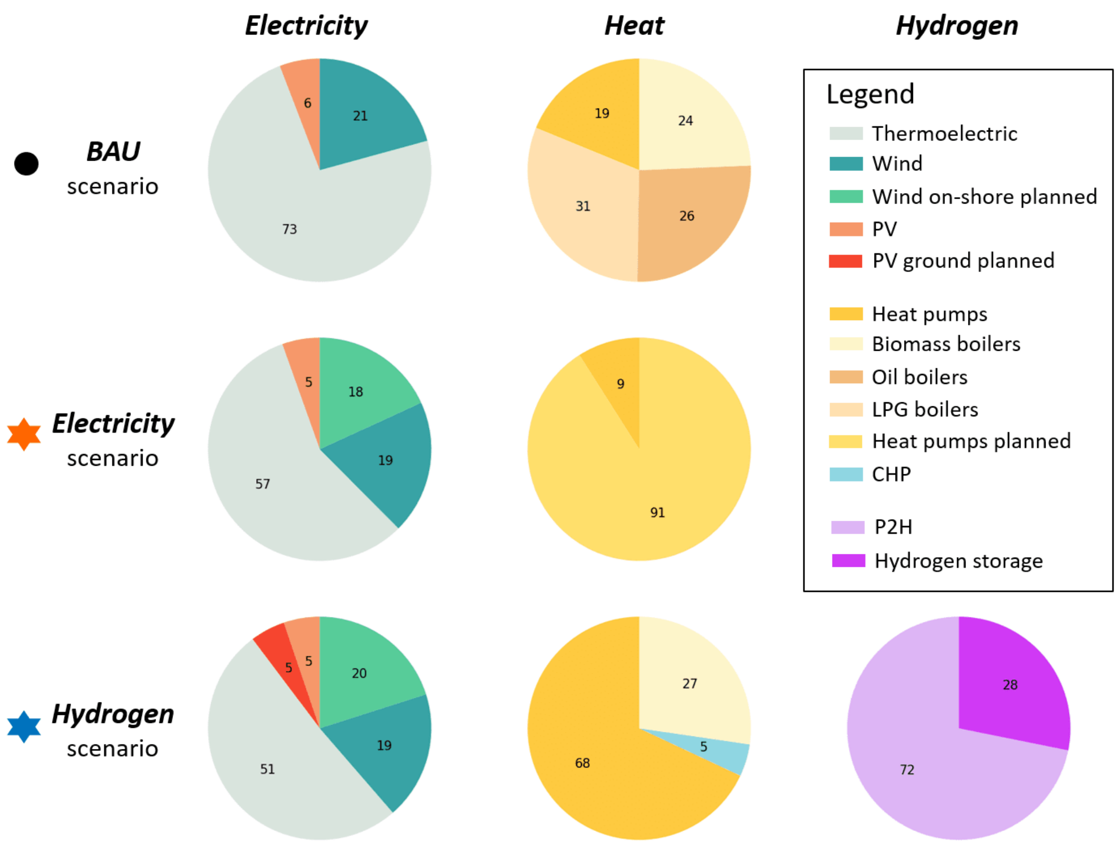


OPTIMAL PLANNING ALTERNATIVES



BAU scenario solution (black) and optimal solutions for the ***Electricity*** (orange) and ***Hydrogen*** (blue) scenario in the **objective space**.

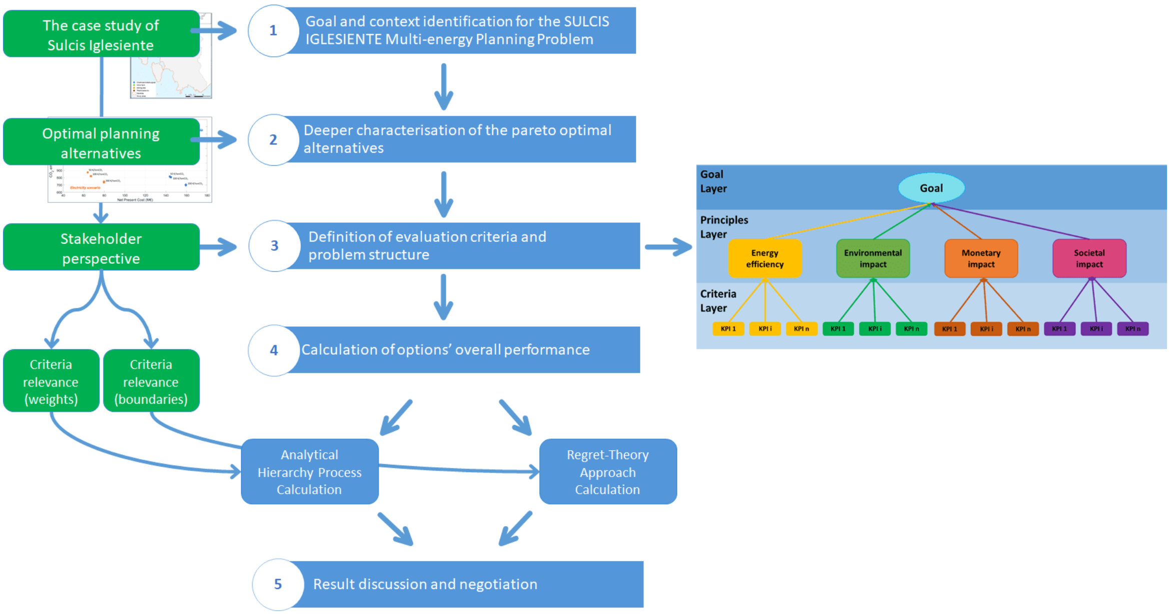
- **Trade-off** between **economic** (NPC) and **environmental** (CO_2 emissions) objectives.
- All solutions characterized by a CO_2 emission cost **dominate *BAU*** scenario solution with respect to the **environmental objective**.
- ***Hydrogen*** scenario solutions are characterized by **higher costs but lower CO_2 emissions** compared to ***Electricity*** scenario solutions.



Energy production share (%) of different technologies for different energy carriers. ***BAU*** scenario solution is compared with the optimal ***Electricity*** scenario and ***Hydrogen*** scenario solutions characterized by a **CO_2 cost of 50 €/ton**.

- ***Electricity*** scenario solution exploits the higher renewable power through heat pumps.
- ***Hydrogen*** scenario solution transforms renewable electricity surplus in hydrogen to be stored and used for heat generation through CHP.

CB-MCA - PROBLEM DEFINITION



CB-MCA methodological flowchart for the case study of Sulcis Iglesiente:

1. Analysis of the main characteristics and **peculiarities of Sulcis Iglesiente**.
2. Deeper characterization of the Pareto optimal alternatives through the **calculation of new attributes** (e.g., installed capacity, energy production).
3. Definition of the **evaluation criteria** according to a hierarchical structure composed of 3 layers.
4. Identification of the **best** Pareto optimal **alternatives** according to the **Analytical Hierarchy Process** or the **Regret-Theory Approach**.
5. **Negotiation** with stakeholders.

Analytical Hierarchy Process

The AHP directly involves stakeholders, who define their preference associated to each criterion (weight). The overall performance of each alternative is calculated by a linear combination of scores and weights and the best alternative is the one with the highest performance.

Regret-Theory Approach

The RTA introduces a decision rule that models the stakeholder behavior within a decision-making problem. The best alternative is the one that minimizes the maximum regret over a set of n scenarios. Each scenario represents a vector of weights associated to the criteria. The overall performance of each alternative for each scenario is calculated by a linear combination of scores and weights.

CONCLUSIONS

Take-home messages

- The proposed methodological framework allows to **support decision makers** in the energy transition process.
- A clear **trade-off between monetary and environmental objectives** poses great challenges in the identification of the best alternatives for shaping the energy transition.
- Although economically unsustainable, **hydrogen-based solutions** could provide significant benefits for the **energy system decarbonization**.
- **CB-MCA methodology** allows to perform a deeper analysis over a set of Pareto optimal alternatives by considering **stakeholders expectations and preferences**.

DISCLOSURES

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ABSTRACT

In the energy transition context, the design of integrated **multi-energy systems** is key for reaching ambitious sustainability objectives. Due to the intermittent nature of the renewable energy sources, introducing technologies for **storing and transforming energy in different carriers** (e.g., electricity, gas, heat) is, in fact, a strategic solution for fully exploiting the renewable power generation, **increasing the flexibility** of the system, and contributing to the **decarbonization**.

Although the need to rely on multi-energy systems is widely shared, identifying their optimal design requires the use of **complex modelling tools** able to **characterize the territory**, simulate the **system dynamics**, and evaluate the solutions with respect to different **sustainability objectives**.

To support the **decarbonization decision-making process**, in this work we develop a **three-step modelling chain** for planning optimal multi-energy systems at the local scale. More precisely, we first perform a **territory characterization** by estimating, through different methodologies, input data of renewable resource availability, territory exploitation potential, and energy demand of electricity and heat.

Then, we carry out a **multi-energy analysis** identifying **Pareto optimal system designs** with respect to two sustainability objectives, namely the **Net Present Cost** and the **CO_2 emissions**.

Finally, we perform an **intersectoral Cost Benefit-Multi Criteria Analysis (CB-MCA)** for evaluating the solutions obtained in the previous step with respect to a wide range of indicators representing energy, economic, and social acceptance aspects. The CBA approach is adopted for evaluating the financial and economic viability of the investment options, while the assessment of non-monetary impacts is performed through the MCA approach.

We apply the modelling chain to the **real case study of Sulcis Iglesiente (Sardinia, Italy)**, a territory characterized by carbon-intensive industries, recently selected for receiving funding from the Just Transition Fund launched by the EU Commission in the context of the Green Deal.

Results demonstrate the validity of the proposed modelling chain in the identification of the **best interventions for supporting the decarbonization** and the sustainable development of Sulcis Iglesiente.

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