Formulation of Clean Energy Transition Strategies for Small and Medium Sized Cities

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1 ABSTRACT

The EU project PLENTY-LIFE has developed the Holistic Integrated Spatio-Temporal Energy Planning (HISTEP) framework to help small and medium-sized cities (SMCTs) plan long-term clean energy transitions (CET). Currently, the framework is being tested in seven pilot cities across Austria, Italy, Portugal, and Romania through a collaborative process with local stakeholders. This paper outlines the key steps in CET strategy development and shares initial findings from applying HISTEP to project future energy demand in Fundão, Portugal. The baseline "business-as-usual" (BAU) scenario reflects historical trends and existing policies, with minimal decarbonization efforts and moderate socio-economic and technological changes. In BAU scenario, the projected annual final energy demand by fuel shows a slight increase from 318.8 GWh to 320.0 GWh over the study period (2018-2050), averaging an annual growth rate of 0.01%. During this period, motor fuel remains dominant, where its share decreases from 47% to 43% of total final energy consumption. Electricity's share increases from 30% to 34%, while fossil thermal fuel decreases from 14% to 12%. The final energy by sector shows a dominance of building sectors, its share will rise from 43.8% to 45.9%, the transport sector decreases from 41.8% to 36.5%, and the industry sector increases from 14.5% to 17.6%. The resulting CO_2 emissions within the city boundaries show a slight decline from 48.6 to 43 kt-CO_2. The corresponding per capita indicator indicators reveal an increase in final energy demand from 11.9 to 14.4 MWh/cap and a slight rise in CO_2 emissions from 1.82 to 1.94 t-CO_2/cap. These results illustrate the limited impact of current decarbonization measures concerning energy savings and efficiency improvements, electrification, digitalization, and the transition to clean fuels across all consumption sectors. BAU scenario serves as a benchmark to assess the effectiveness of the forthcoming clean energy transition scenario (CETS), which aims to demonstrate a decarbonization pathway toward a climate-neutral Fundão by 2050. The CET aligns with Fundão's energy and climate goals and is driven by significant enhancements in energy efficiency across all sectors, electrification of end-uses, a shift to clean fuels, and an increase in local RES to decarbonize power and heat supply.

The HISTEP framework's application in Fundão underscores the importance of comprehensive, integrated planning in achieving sustainable energy transitions for SMCTs. Modelling various scenarios following a participatory process engaging local stakeholders and citizens, cities can develop tailored strategies that effectively address their unique challenges and opportunities in the journey toward carbon neutrality.

Keywords: sustainable urban development, spatio-temporal energy planning, city decarbonisation strategy, Co-creation , Clean Energy Transition

2 INTRODUCTION

Achieving climate neutrality requires transitioning to a resource-efficient, sustainable, and low-carbon energy system. Cities, responsible for around 70% of global energy consumption and CO_2 emissions (IRENA, 2020), (UN-Habitat, 2019), (Fuso Nerini et al., 2019) play a crucial role in this shif. With urban populations projected to rise from 55% to 68% by 2050, many European cities have set ambitious decarbonization goals. However, SMCTs often lack the resources for comprehensive strategies, leading to fragmented efforts.

To address this, the EU project PLENTY-LIFE is developing an integrated urban energy planning framework to help SMCTs formulate and monitor long-term CET strategies, aiming for climate neutrality by

2040/2050. The framework is being tested in seven pilot cities across four EU countries, paving the way for broader adoption. Key project areas include:

- HISTEP Framework: A bottom-up urban energy planning approach, modeling future energy demand and supply along CET pathways aligned with socio-economic and technological trends.
- Pilot Cities: Seven case studies in four EU countries demonstrate HISTEP's integration into planning processes.
- Capacity Building: Three training modules enhance local expertise in energy, spatial, and urban planning, targeting policymakers and planners.
- Participatory Process: Engages local stakeholders through co-design, co-creation, and co-learning, including stakeholder mapping, feasibility tools, and workshops.
- CET Strategy Formulation: A five-step approach involving data collection, model calibration for the base year, scenario development, sectoral prioritization, and monitoring, with stakeholder input through workshops and surveys.
- Replication and Scaling: Extracting best practices from pilot cities to support other European SMCTs in developing CET strategies.

This paper presents the CET strategy framework and its application to Fundão[1], Portugal, focusing on projected energy demand by 2050 under a BAU scenario, which serves as a benchmark for future CET scenarios.

3 METHODOLOGY

Transitioning SMCTs to carbon neutrality requires an integrated, cross-sectoral energy planning approach embedded in urban planning. The HISTEP framework, developed within PLENTY-LIFE, combines spatio-temporal energy-demand and supply analysis with advanced urban energy modeling tools to assess flexibility needs (Horak et al., 2022), (Hainoun and Loibl, 2022). It also provides a monitoring framework (KICET) aligned with SDGs 7, 11, and 13.

A co-creation process involving local stakeholders and citizens – through workshops and surveys – guides the development of CET strategies via the following steps:

- Data Collection: Gather current energy balances by sector and fuel, assess RES potentials, and compile socio-economic and technological parameters influencing the city's energy demand and supply.
- Base Year Calibration: Reconstruct and calibrate the base year energy demand and supply to establish a reference point for future projections.
- Scenario Development: Build BAU and CET scenarios through active engagement with key stakeholder.
- Energy Demand-Supply Modelling: Utilize established framework tools MAED-City, CEA, and MESSAGE, to model energy demand and supply, and extract pertinent results.
- Stakeholder Feedback: Refine scenarios to align with city energy and climate targets.
- Key Indicators for CET (KICET): Extract a set of indicators to monitor the progress and effectiveness of the CET strategy.
- Roadmap and Priority of Action: Define a transition roadmap with prioritized actions.

The HISTEP approach ensures CET strategies are data-driven, inclusive, and tailored to city-specific needs, increasing their effectiveness and stakeholder acceptance.

The focus of this paper is on presenting the so far accomplished work of applying the HISTEP methodology to prepare the CET strategy of the pilot city Fundao. Thus, the presented content covers the data collection, base year reconstruction and calibration, development of BAU scenario for the final energy demand

[1] http://plenty-life.eu/portugal/

projection, and elaborating on the conducted work to construct the CETS including related stakeholder and citizen engagement.CASE Study: Fundão city

4 CASE STUDY: FUNDÃO CITY

Fundão, a municipality located in the Castelo Branco District, occupies an area of approximately 700 km² and its population accounts to 26,706 inhabitants (Gabinete de Estratégia e Estudos, 2024). Fundão benefits from its proximity to three important urban areas of polycentrism in the Centre Region, namely Covilhã to north, Guarda to the northeast and Castelo Branco to south (Fig. 1). As a low-density rural territory, agricultural production, complemented by a strong commercial tradition in the city of Fundão, is the region's main sector and has been for centuries. With a population density of approximately 38 inhabitants per km², Fundão's residents are primarily concentrated in urban areas, a common pattern in low-density regions. However, the municipality's population is rapidly declining. While the negative growth rate was only 0.1% in 2001, it had increased tenfold by 2021, and this trend is expected to worsen.

Fundão's economy is heavily reliant on agriculture and a well-established, diverse trade network. Among its agricultural products, the renowned "Cereja do Fundão" stands out, generating over 20 million euros annually and playing a crucial role in the local economy. The sector comprises over 300 producers and employs more than 2,000 seasonal workers each year. Meanwhile, the industrial and trade sectors have diversified in recent years, with notable contributions from the glass, granite, wood, and jewelry polishing industries.

Demographic trends reflect significant shifts. The labor force constitutes approximately 57.4% of the population, but this share is steadily decreasing, while the elderly population (over 65) has risen to 32.5%, a trend that began in the 1960s. Simultaneously, the proportion of younger residents (under 15) declined from 11.8% in 2011 to 10.1% in 2021.

Like demographic changes, the employment landscape is evolving. Agriculture employs a relatively stable 6.5%-6.8% of the workforce, while the industrial and construction sectors have seen a gradual decline, dropping from 27.2% in 2011 to 25.7% in 2021. Conversely, the service sector has grown significantly, from 53.7% in 2001 to 67.4% in 2021, although its growth has slowed in recent years.

Fig. 1: Geographical location of Fundão within the central region of Portugal (Rowe, 2021).

Fundão faces several challenges, typical of landlocked municipalities, which have profoundly affected its demographic and economic landscape:

- An economic downturn due to limited private investment and weak innovation in local industries.
- Population aging driven by declining birth rates.
- Outmigration of younger, skilled individuals to larger urban centers or abroad.

These issues have also led to urban decline, with the historic city center suffering from degradation and a loss of identity. Additionally, rural abandonment and underutilization of the region's natural resources remain significant barriers to economic development.

4.1 Status of Urban Development of Fundão

By focusing on attracting investment, retaining talent, creating jobs, and opening new markets, Fundão's Innovation Plan aims to enhance the region's competitiveness and appeal (Câmara Municipal de Fundão, 2024). Today, Fundão thrives as a hub of open innovation, supported by enterprise hosting facilities, co-working and incubation spaces, a globally certified Fab Lab, a Business and Services Centre meeting top industry standards, an Advanced Training Centre for upskilling and reskilling, the Agrotech IoT Centre, a Temporary Work Reception Centre, and a Software Verification and Certification Centre. This strategy has attracted significant investment, transforming Fundão into a global innovation hub. Over 1,000 technology-sector jobs have been created, and 16 ICT companies have established operations in the region, exporting much of the knowledge produced locally.

Beyond its innovation ecosystem, Fundão, an historic city with roots in trade, features a well-structured street network. The municipality also provides a train station and an intercity bus stop. Due to the city's compact size, it is easily walkable, eliminating the need for an intracity public transport system with a positive implication to the city's CET. However, despite its walkability, 67.7% of the population commutes by car, while only 8.9% use public transport. The new commercial centers have been located outside the city, causing this need to commute by car. Fundão is also well-connected via a highway linking it to three major urban centers: Covilhã (35 km), Guarda (70 km), and Castelo Branco (43 km). This access to key economic hubs is crucial for attracting businesses and supporting their growth in the region. Although Fundão offers good train and intercity bus connections, there are no public transport options within the city itself, leading most residents to rely on cars. Fundão does have a few cycling lanes for recreational activities, and as part of the European project "Mobility Urban Values", plans are underway to expand the cycling network.

In terms of housing, in 2021 the total number of dwellings in Fundão is about 18,882, where the main residences and the secondary residences are included (SPI Technical Team, 2023). Based on these total number of dwellings and the total number of population of approximately 26,700 (SPI Technical Team, 2023), the household size in Fundão is about 1.4 persons per household. In 2011 the household size was about 1.6 persons per household (SPI Technical Team, 2023) and so for the base year 2018 the household size was set up with 1.5 persons per household. Nearly half of these households have been issued an energy certificate of class B or higher (ADENE – Agência para a Energia, 2023). Given the historic nature of the municipality, ongoing renovation efforts have contributed to this significant share of energy-efficient buildings. However, it is important to note that this figure applies specifically to the residential sector.

4.2 Energy and Climate Targets: National and Municipal Commitments

Portugal aims to reduce the greenhouse gas emissions in the order of 45% to 55% from 2005 levels by 2030.

A significant component of this strategy is increasing the share of renewable energy in final energy consumption to 51% by 2030, up from the previous target of 47%. In the electricity sector, the objective is even more ambitious, with plans to generate 93% of electricity from renewable sources by 2030. The overall installed renewable energy capacity will rise to 42.9 GW by 2030. These efforts are part of Portugal's revised National Energy and Climate Plan (NECP 2030), which outlines the country's commitment to enhancing energy efficiency, diversifying energy sources, and reinforcing infrastructure to support the energy transition (European Commission, 2024). By implementing these measures, Portugal aims to reduce its dependence on fossil fuels, enhance energy security, and position itself as a leader in renewable energy within Europe.

The Municipality of Fundão has implemented various sustainability initiatives such as the development of the Sustainable and Intelligent Interurban Development Action Plan (PADISI) in 2018 and Sustainable Energy and Climate Action Plan (SECAP) in April 2023. PADISI promotes a low-carbon economy and energy self-sufficiency in the Alentejo-Centro-Extremadura Euroregion (EURO–ACE). The SECAP outlines goals to reduce CO2 emissions by at least 40% by 2030, increase resilience to climate impacts, and improve energy efficiency through six mitigation sectors (Municipal buildings, non-municipal buildings, residential buildings, industry, primary sector, transport) and thirteen adaptation sectors (buildings, transport, energy, water, waste, land use planning, agriculture and forestry, environment and biodiversity, health, civil protection and emergency, tourism, education, ICT). Additionally, the plan addresses energy poverty across six macro areas (climate, socio-economic aspects, housing, mobility, regulatory policy, participation/awareness-raising).

Category	Measure
Sustainable Buildings	Enhance thermal comfort, passive resilience, and energy and water efficiency in buildings by prioritizing the use of advanced, efficient technologies. Decarbonise the building stock.
Sustainable Mobility	Foster sustainable transportation by supporting the energy transition in the transport sector and promoting universal accessibility and efficient travel behaviors.
Renewable Energy Production	Facilitate the decarbonization of the municipality and boost energy self-sufficiency by engaging the community as active participants in the energy system.
Sustainable Networks	Improve the efficiency of public infrastructure and resource management to minimize waste and enhance territorial resilience.
Sustainable Natural Assets	Strengthen resilience, value natural capital, and promote a balanced rural economy and environmental sustainability.
Ecological, Just, and Cohesive Transition	Integrate ecological and sustainable principles into municipal policies and practices, raising awareness and encouraging citizen participation in sustainable production and consumption.

Table 2: Qualitative municipality targets (SPI Technical Team, 2023)

Fundão's commitment to sustainability is further reflected in its improving energy efficiency and promoting renewable energy, attracting private investments in clean energy. Fundão now produces more energy than it consumes, with renewable energy production reaching 423 GWh in 2020, far exceeding its own consumption of 92 GWh. This energy surplus is expected to grow with upcoming investments, positioning Fundão as a regional leader in clean energy production.

4.3 Data Collection and Base Year Calibration

The energy consumption presented refer to the main consuming sectors: agriculture, construction, mining, manufacturing, household, service and transportation (passenger and freight).

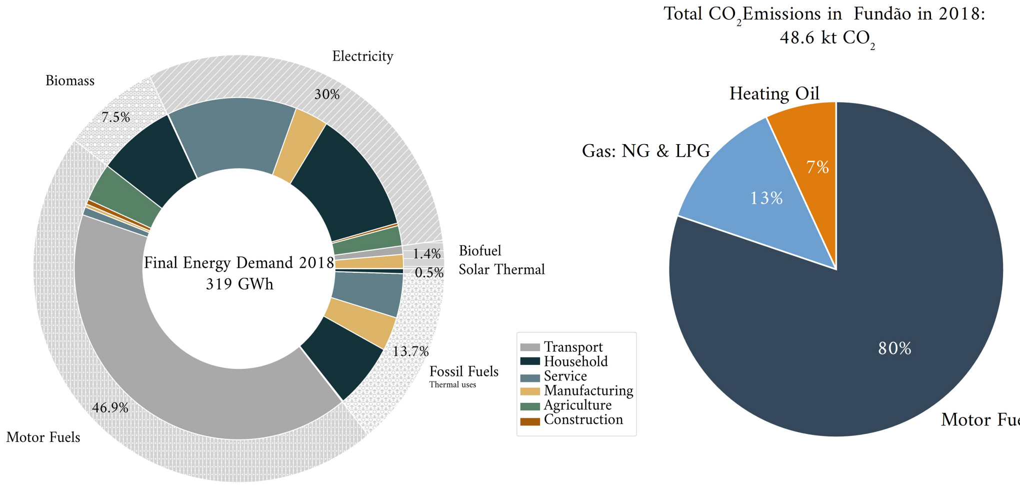


Fig. 2: Final energy consumption by sector and fuel type (on the left-hand side) and CO_2 emissions by fuel type in Fundão in 2018 (on the right-hand side).

4.3.1 Energy Demand of Fundão in the Base Year 2018

When compared to national energy indicators, Fundão's energy intensity and per capita energy consumption are both lower than the national average. In 2018, the total final energy consumption in Fundão reached approximately 318.8 GWh, distributed to 41.8% for mobility (freight 13.6% and passenger transportation 28.18%), 26.1% for households, 17.7% for services, 8.1% for the manufacturing industry, 5.6% for agriculture and forestry, and 0.8% for the construction sector. The energy demand breakdown by fuel highlights the dominance of fossil motor fuels, which account for 46.9%, primarily used in the transport sector. Electricity makes up 30.0%, mainly consumed by households and the service sector. Fossil fuels for thermal use account for 13.7%, shared between households, services, and manufacturing, while firewood at 7.5%, as shown in Fig. 2.

The resulting direct CO_2 emissions of Fundão reached in the base year 2018 around 48.6 kt CO_2 with the primary source represented by fossil motor fuels, followed by gas (natural gas and LPG) and heating oil as depicted in Fig. 2. The significant share of emissions from fossil motor fuels in the base year 2018 highlights the critical importance of implementing effective mitigation strategies in the transport sector as elaborated later by the development of the CET strategy of Fundão.

4.3.2 Energy Supply of Fundão in the Base Year 2018

Fundão hosts several renewable energy power plants, with the largest being a forest biomass thermoelectric plant, boasting an installed capacity of 15 MW (Power Technology, 2024). This plant generates around 120 GWh of electricity, with a capacity factor of approximately 0.91. In addition, the municipality has 2.38 MWp of installed PV capacity (Observatório Fotovoltaico, 2023). According to GEM (Global solar power tracker, 2023), an additional 110 MW of solar PV is currently under construction. Fundão does not have a district heating network, and all households rely on individual heating systems powered by either fossil fuels or biomass.

4.4 Scenario Development

Following the steps elaborated above in the methodology section the development of CET strategy starts with the modelling of final energy demand which has been conducted using the bottom-up model MAED-City (Hainoun and Loibl, 2022) that constitues a module within the HISTEP framework. The first step dealt with the reconstruction of the base year 2018 to clibrate the relation between sectoral end-use energy consumption and the demographic, socio-economic and technological determinants controlling the useful and final energy demand. Starting from the calibrated base year the future development scenarios are constructed following the expected long-term development of demographic, socio-economic and technological drivers up to 2050.

The expected future trends for these drivers are exogenously introduced based on official references (e.g. city future development strategy and plans, local and nation energy and climate goals), stakeholder workshops, citizen survey, bilateral communications with the city stakeholder and expert judgements. Each scenario starts with a storyline describing the future vision of the perceived development path.

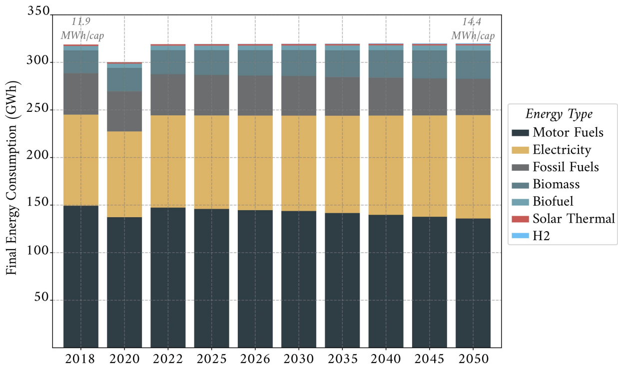
The key aspect in the scenario development is to ensure internal consistency among the different assumptions of the key drivers. Considering that the resulting future energy demand is just a reflection of these assumptions. Two development scenarios have been considered – BAU and CET scenario – describing two pathways of the Fundão’s future socio-economic and technological development over the period 2018-2050.

The scenario results of MAED-City are always of the conditional type to project a possible future development trajectory allowing for analyzing the impact of different socio-economic development policies of the city, e.g., different economic growth in industry and service activities, changes in the lifestyle of society like individual car vs. public transport, Impact of technological development reflected in new market penetration rates and related equipment efficiency, new policy targets of clean energy transition. This contribution focuses on the development of BAU scenario.

4.4.1 Development of BAU scenario

The BAU scenario follows historical trends and enacted policy measures characterised by low moderate socio-economic and technological changes and limited decarbonisation measures concerning energy savings and efficiency improvements, electrification, digitalization, and the transition to clean fuels across all consumption sectors. BAU scenario serves as a benchmark to assess the effectiveness of the forthcoming CET scenario, which aims to demonstrate a decarbonization pathway toward a climate-neutral Fundão by 2050.

Fig. 4 represents the resulting development in the BAU secenario of the final energy demand by fuel and sector for the municiplality of Fundão. The total demand will grow by an average annual rate of 0.01% from 318.8 GWh in 2018 to 320.0 GWh in 2050. The consumption of biomass (firewood) recorded the largest annual increase with 0.71% p.a. followed by biofuel (gasoues, liquid, solid- e.g. wood chips) with 0.43% p.a. The final energy demand will be mainly dominated by motor fuel whose share in final energy consumption will slightly decrease from 47% (2018) to 43% by 2050, followed by electricity that will increase from 30% (2018) to 34% by 2050, and fosill fuel that will decrease from 14% (2018) to 12% by 2050. The results illustrate the trend development of limited penetration of energy efficiency measures and clean fuel usage. This effect is especially pronounced in the building sectors (service and household sector) showing limited switch from fossil fuel to renewable energy sources or showing less energy efficiency measures as set in the CET scenario. The result is that the final energy demand of the household sector increases from 83.1 GWh/a (2018) to 87.6 GWh/a (2050) and of the service sector from 56.4 GWh/a (2018) to 59.5 GWh/a (2050), which are the dominating sectors of the total energy demand of Fundão by 2050. The increase in final energy demand in the building sectors is due on the one hand to the increase in dwelling sizes and heated areas of the different housing types and on the other hand to the use of vacant dwellings. The building sectors (household and service) have in 2050 a share of 46%, followed by the passenger transportation sector with 23% and the freight transportation sector with 14% of the total final energy demand as illustrated in Fig. 4. The corresponding final annual energy demand per capita shows an increase from 11.9 to 14.4 MWh/cap.



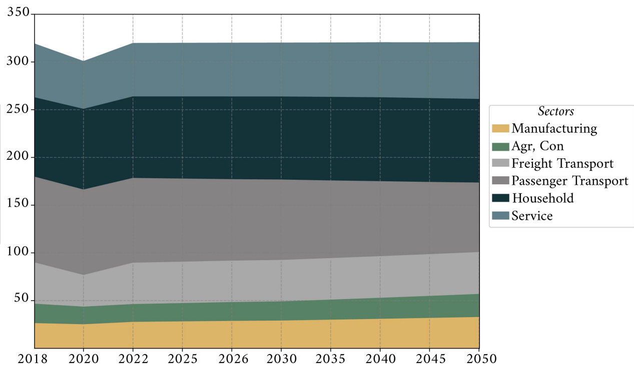


Fig. 4: Fundão's final energy demand projection by fuel type (left) and by sector (right) for the BAU Scenario.

Following the projected final energy demand by sector of BAU the development of energy-related CO_2 emissions within the city boundaries has been calculated as shown in Fig. 5. The results depict the dominance of motor fuel accounting for 80.2% in 2018 and increased to 82.2% in 2050. This trend is primarily driven by fossil fuel consumption in the transportation sector, as well as in agriculture and construction. This illustrates, that to reach climate neutrality by 2050, the municiplaity of Fundão should implement effective decarbonistaion measures in the transportation sector. Strategies include transitioning from fossil-fueled vehicles to EV, promoting a shift from individual to public transportation, and encouraging active modes of transport such as biking and walking within the city.

Furthermore, Fig. 5 highlights that natural gas is predominantly used in the manufacturing sector (52% of total gas consumption), followed by households (24%) and the service sector (23%). Its extensive use in Fundão presents a significant opportunity for decarbonization through the adoption of renewable energy sources and electrification measures. Additionally, heating oil is expected to be phased out in Fundão's BAU scenario by 2040.

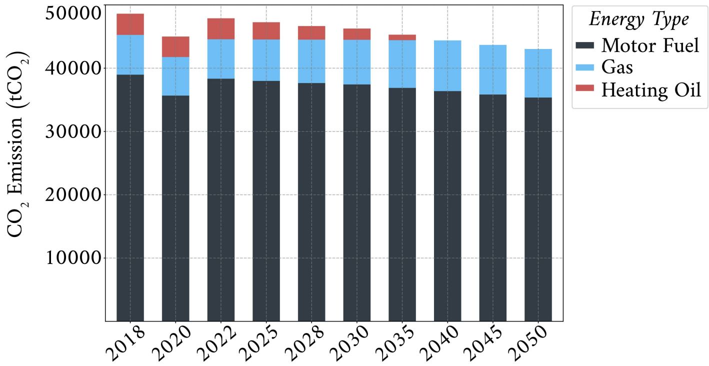


Fig. 5. Projection of the CO_2 emissions for the municipality of Fundão until 2050 (BAU scenario).

The total CO_2 emissions in Fundão decrease by -0.38% p.a. from 48.6 kt CO_2 in the base year 2018 to 43.0 kt CO_2 by 2050. Due to the expected population decline in Fundão of around -0.57% per year from 2018 to 2050, the CO_2 emissions per capita will increase from 1.82 to 1.94 t CO_2 per capita.

4.4.2 Development of Clean Energy Transition scenario (CETS)

The CETS aligns with Fundão's energy and climate goals and is beeing developed based on the results of BAU employing significant enhancements in energy efficiency, electrification of end-uses and a shift to clean fuels across all sectors beside increasing the share of local RES to decarbonize power and heat supply. As a result, significant shifts will occur in city's final energy demand and supply structure, the technological landscape of energy production and consumption, and the changes in related socio-economic and technological determinants. Fig. 3 illustrates the key decarbonisation drivers for developing the CET scenarios.

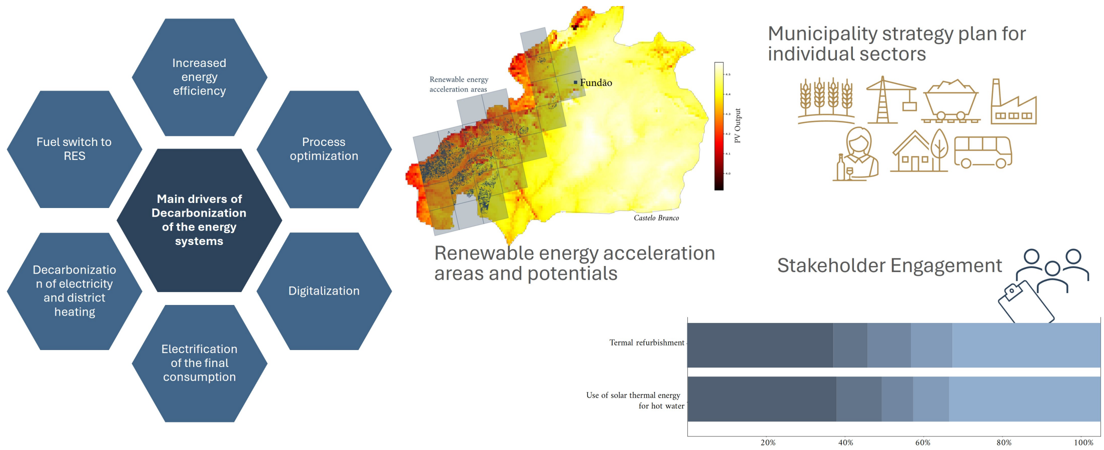


Fig. 3: Framework for Modeling CET scenarios in cities.

Decarbonization across all sectors relies on reducing energy demand, improving efficiency, and integrating renewable energy sources. In the building sector, measures such as thermal insulation, high-performance glazing, energy-efficient appliances, and advanced HVAC systems significantly lower heating and cooling demand, while refurbishment minimizes energy losses. Industrial decarbonization focuses on process optimization and waste heat recovery through technologies like heat exchangers and combined heat and power systems, which enhance energy utilization and reduce emissions. Digitalization plays a key role in improving energy efficiency, with smart meters, AI-driven management, and automated control systems enabling real-time energy optimization and grid stability. The electrification of transport, heating, and cooking – through the adoption of electric vehicles, heat pumps, and induction-based systems – reduces reliance on fossil fuels and shifts energy demand towards renewables. Additionally, expanding district heating networks and increasing the share of renewable energy sources such as solar, wind, geothermal, and biomass further supports the transition to a low-carbon energy system.

To effectively model clean energy transition scenarios, it is essential to assess the spatial and technical potential for renewable energy deployment while aligning sectoral decarbonization strategies with urban planning objectives. Additionally, municipalities must align their strategic plans with the unique needs of different sectors, since each sector has different energy demands, and targeted approaches are needed to decarbonize them.

Equally important is engaging stakeholders in the process. By involving local businesses, communities, and policymakers through surveys and consultations, citizens willingness to invest in clean energy strategies and determine what percentage of them is likely to adopt these solutions can be gauged. This input will provide valuable insights into the practical feasibility and acceptance of proposed measures.

4.5 Citizen Engagement

The clean energy transition are not just technical challenges, they are social ones. A key aspect of the project implementation is strong stakeholder engagement, ensuring the active involvement of key actors in the pilot cities. This facilitates collaboration with local stakeholders who contribute to the development of CET strategies, monitor results, and support the creation of realistic action plans.

To create truly sustainable and livable cities, we must move beyond top-down planning and embrace co-creation, where citizens actively shape the future of their communities. People are not just end-users of policies; they hold valuable local knowledge, and the power to drive change. When citizens are engaged, solutions become more inclusive, effective, and widely accepted, reducing resistance and fostering long-term commitment.

4.5.1 Citizens Survey

This study presents the findings of a citizen survey conducted to assess public perceptions, behaviors, and awareness of energy use and climate change, providing valuable insights into societal attitudes and potential policy implications. The questions asked in different domains cover couple of options for citizens to rank from "not relevant" to "very relevant".

The Fig. 6 illustrates citizens' opinions regarding the domains of buildings energy savings. Most participants ranked thermal insulation as the preferred measure for achieving heating energy savings. For reducing cooling energy demand, the most common response was the installation of a photovoltaic (PV) system to cover their own energy needs.

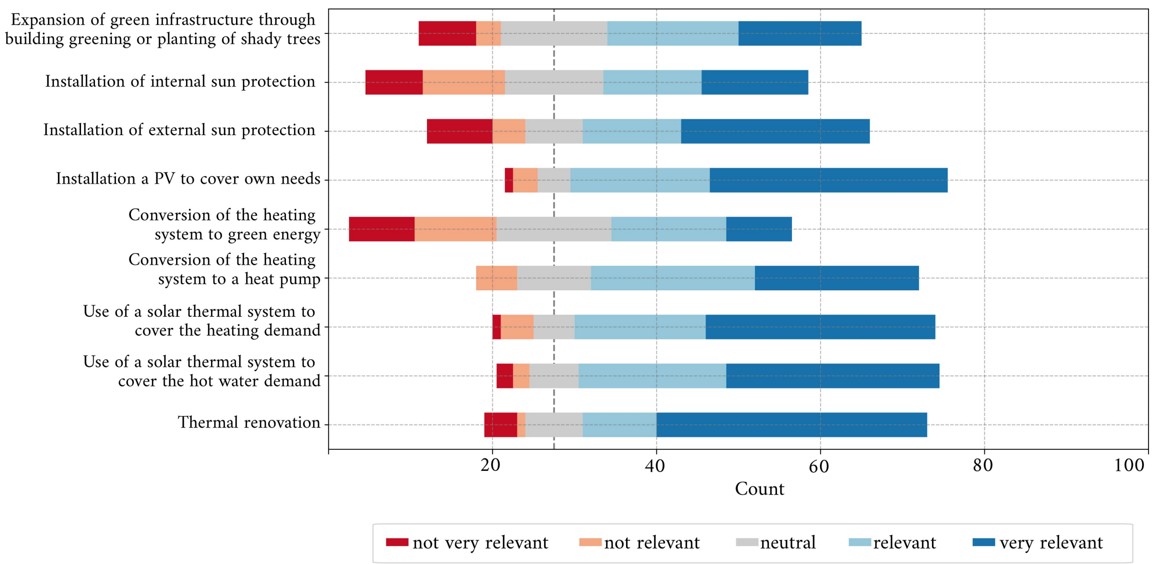


Fig. 6. Citizen ranking on "Which measures would you be most likely to implement to achieve energy savings (heating and cooling) in your own house/apartment?"

The most commonly owned vehicle among participants is a diesel car. In contrast, electric vehicles (EVs) are not prevalent within the surveyed group. The Fig. 7 presents citizens' views on the relevance of mobility. The most participants indicated that the expansion and promotion of public transportation is the most critical area for the improvement.

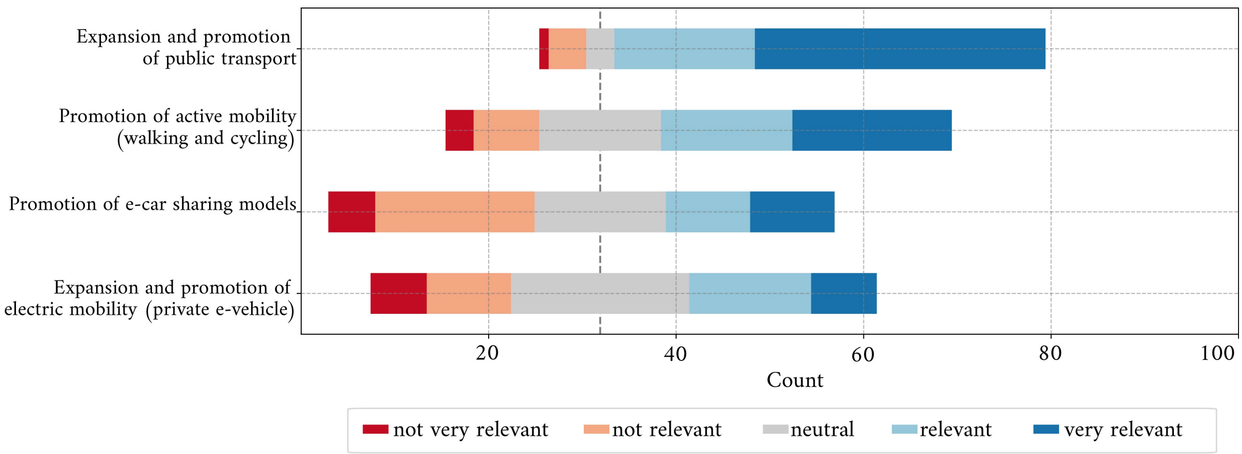


Fig. 7. Citizen ranking on "Where is the greatest need for action to achieve the climate goals of your municipality concerning mobility?".

The Fig. 8 illustrates citizens' opinions on achieving climate goals of municipality. Most of the participant find the consumption of local goods are in greatest need. Walking and cycling follows this.

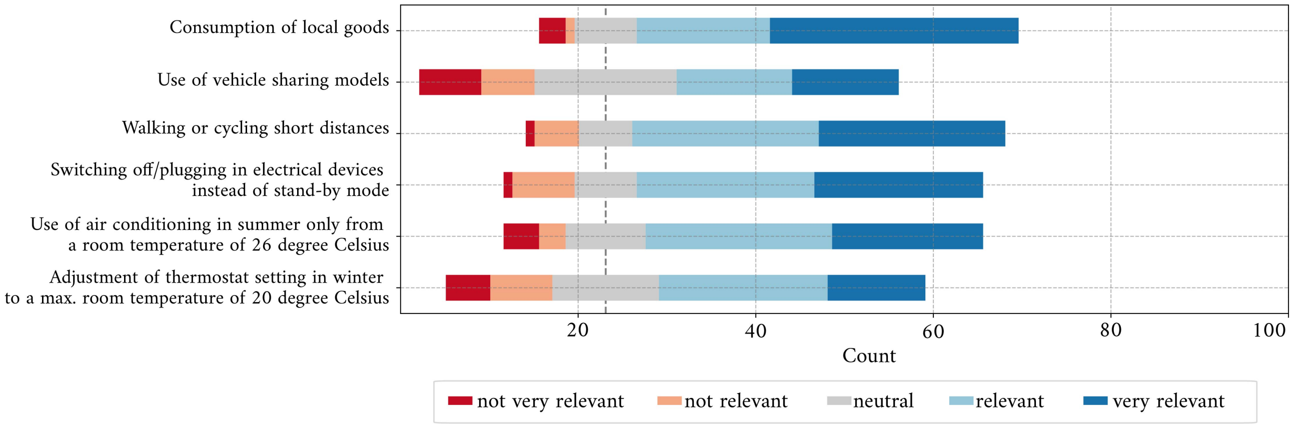


Fig. 8. Citizen ranking on "Where is the greatest need for action to achieve the climate goals of your municipality/city?"

4.5.2 Workshop2 – Ranking the importance of transformation sectors

To collaboratively establish measurable CET targets for the city, a matrix outlining the transformation sectors (agriculture, buildings, cross-sectors, industry/service, and mobility) and the corresponding measures (energy efficiency, fuel switch, socio-economic, and other measures) is generated to rank the importance of these topics for 2030. Fig. 9 displays the heatmap of the result from the ranking processes. According to the citizens the most important measures within the cities are i) fuel switch in the buildings, ii) other measures in the cross sectors, ii) socio-economic measures in industry/service sector.

The lowest-ranked measures are those where development relies heavily on technology, leaving citizens with little influence. As a result, they did not prioritize these measures in their votes. For example, in the mobility sector, energy efficiency received low rankings because citizens have limited control over it, lack awareness, and do not fully understand its impact. Similarly, in the agriculture sector, switching fuel sources was ranked low for the same reasons.

The highest-ranked measures are those where citizens can have a direct influence. For example, in the building sector, fuel switching is a priority, with many new buildings opting for solar thermal water heaters. In the industrial sector, socio-economic measures, such as the expansion of industrial zones to support business growth, ranked highly. Cross-sectoral factors, such as population decline due to an aging population, were also considered significant.

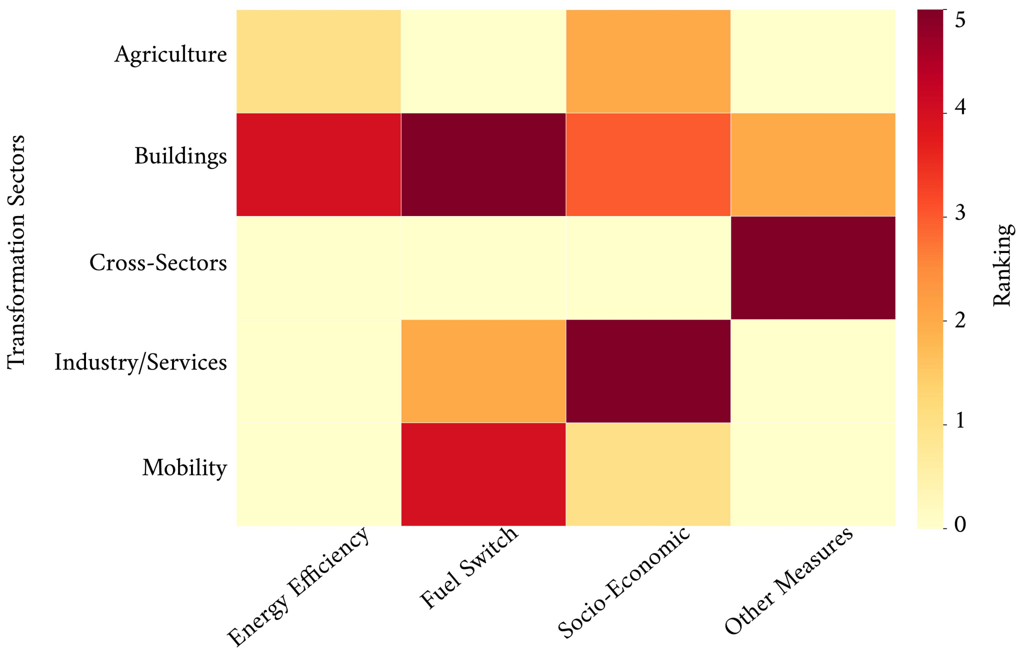


Fig. 9. Citizen workshop results for defining importance of the measures in transformation sectors for 2030.

5 CONCLUSION

The Plenty-Life project demonstrates a comprehensive approach to supporting SMCTs in delivering their clean energy transitions strategies. By integrating integrated urban energy modeling, stakeholder participation, and capacity-building programme, the project aims to empower local authorities to formulate tailored, long-term decarbonization strategies. The case study of Fundão serves as the first example of the framework's practical implementation, addressing critical challenges such as demographic shifts, reliance on fossil fuels, and sectoral inefficiencies in energy consumption.

Key findings of BAU scenario illustrate the limited impact of the embloyed measures concerning energy savings and efficiency improvements, electrification and the transition to clean fuels across all consumption sectors. However, they indicate the high decarbonisation potential, particularly in the transportation and building sectors. Such measures will be realised in the ambitious CETS which is driven be effective decarbonisation measures in all sectors. However, achieving the CET traget will require high investments in infrastructure, intensive deployment of renewable energy sources, and enhanced policy coordination at both municipal and national levels.

Stakeholder involvement and citizen engagement, demonstrated through workshops and surveys, have proven essential for ensuring that energy strategies align with local priorities and are socially accepted. While citizen participation in the development of clean energy transition scenarios provided valuable insights, it also underscored the limitations of relying solely on public input. Effective scenario planning requires a balanced approach that combines citizen perspectives with expert knowledge, socio-economic viability, technological feasibility, and policy frameworks. To strengthen this process, the project aims to actively involve a diverse range of stakeholders, ensuring broader awareness, engagement, and more comprehensive clean energy transition strategies. However, significant challenges remain. Limited funding, ristricted data accessibility, and technological barriers may hinder the implementation of the delivered strategies and their replication in other cities. To address these issues, further research is needed to refine energy planning models, explore innovative funding mechanisms, and assess the long-term impacts of policy interventions.

Overall, the Plenty-Life project underscores the importance of integrated planning frameworks in achieving climate-neutral cities. By fostering collaboration among stakeholders and leveraging data-driven insights, the project provides a replicable model for sustainable urban transformation across Europe. The next phase will focus on finalising the CET strategies for the pilot cities, disseminating best practices and supporting follower cities in implementing tailored strategies for a cleaner, more resilient future.

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