CITIES IN ENERGY TRANSITION: LOCAL RESPONSES TO NATIONAL CHALLENGES

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Given that cities are major consumers of energy and significant sources of carbon dioxide emissions, this research aims to explore pathways for their decarbonization. At the same time, recognizing that cities are not isolated energy islands but integral parts of national energy systems, the study investigates how the Energy Sector Development Strategy of the Republic of Serbia up to 2040 with Projections up to 2050 can be effectively scaled and adapted to the local context, using the city of Kragujevac as a case study. Three development scenarios were analyzed: Scenario 1: implementation of National Development Strategy measures that are feasible at the local level: Scenario 2: enhancement of the Strategy by incorporating local potentials not currently addressed in the national framework, and Scenario 3: further development of the district heating system to enable greater integration of renewable energy sources.

The research employs a multi-criteria decision analysis (MCDA) approach, involving diverse stakeholders, including citizens, academia, NGOs, and local policymakers. Through surveys, priority criteria for evaluating the proposed measures were identified, enabling a comparative analysis of the scenarios.

The results provide valuable insights into local preferences and capacities for energy transition and offer recommendations for improving strategic alignment between national and local energy planning.

Key words*: energy planning, cities, local energy transition, EnergyPLAN, decarbonization,*

1. Introduction

Mitigating the effects of global warming is only possible through a transformation of the energy system, from high-carbon technologies to systems characterized by a high integration of renewable energy sources (RES) and low-carbon technologies. Given that cities are home to nearly 60% of the global population [1] and account for more than 75% of total primary energy consumption [2], urban energy activities must not be overlooked. Urban areas should not only respond to climate goals but also meet the growing energy demands of an expanding population. As such, they represent both major contributors to emissions and key arenas for potential solutions. Therefore, the development of local energy policies must be prioritized [3]. However, energy planning and transitions in cities are often overshadowed by national policies [4], constrained by limited budgets and capacities to formulate climate responses [5]. This frequently results in short-term energy goals [6], typically focused on improvements within a single energy sector [7], thereby limiting the full utilization of a city's energy potential. Future energy systems require a comprehensive approach that fosters the creation of smart energy systems. Such an approach enables a holistic view of the energy sector, promotes sectoral integration, and facilitates more efficient incorporation of RES [8]. Moreover, treating energy sectors in isolation leads to fragmented actions among local stakeholders, researchers, experts, community representatives, and decision-makers, posing a significant challenge to urban climate action, which can only be effective through coordinated efforts [9]. Strategic energy planning aimed at RES-based systems must be grounded in strong linkages between national and local levels, through a long-term process that fosters learning and continuous improvement [10]. Accordingly, downscaling national energy strategies and plans to the local level is of critical importance. Implementing concrete measures locally enables the establishment of realistic targets and facilitates the development of long-term energy strategies aligned with national objectives [11]. Strengthening the connection between national and local energy policies can also help overcome existing barriers and challenges, positioning cities as central hubs of the energy transition. A review of existing research clearly indicates that local-level energy planning is essential for achieving energy transition goals at both global and national scales [12]. Local decarbonization not only maximizes the use of territorially specific RES capacities but also contributes to long-term improvements in citizens' quality of life. In this way, cities can transform from energy consumers into energy producers, fostering a sustainable and diversified energy mix [13] and enhancing the stability of the national energy system.

Finally, it is crucial to communicate the outcomes of energy transitions to the public by clearly highlighting their environmental impacts. Presenting transparent methodologies and outlining technical, economic, and ecological implications enhances understanding,not only among local decision-makers but also among citizens, thereby fostering broader public acceptance.

2. Review of Existing Research at the European Level

Initial planning and analysis of future energy systems were predominantly conducted at the national level, with limited attention given to global or sub-national scales [14]. However, as the importance of cities in the energy transition process has become increasingly recognized, urban areas have emerged as a growing focus of scientific research [15]. These analyses are crucial, as the transition to a low-carbon system is a complex process that requires changes in technology, legal and regulatory frameworks, and various social dimensions [16]. In the existing literature, urban decarbonization has often been approached through the lens of a single energy sector, such as transportation [17, 18] or by examining the potential for deploying specific technologies, such as photovoltaic or solar collectors [19–21]. Additionally, the energy transition in cities has frequently been analyzed from the perspective of decarbonizing the heating sector, primarily through increased use of RES and heat pumps [22, 23]. While such approaches can contribute to emission reductions, they do not facilitate sectoral integration and limit the exploitation of cities' overall energy potential.

Cross-sectoral integration in local decarbonization efforts has been explored in several European cities (Figure 1), using various methodological approaches. In cities such as Zagreb, Croatia [24], and Frederikshavn, Denmark [25], studies have examined local potentials and the interconnection of different sectors and technologies to achieve 100% renewable energy systems. However, these analyses often overlook national targets, focusing solely on local emissions in energy-intensive sectors such as industry and transport. This approach can create implementation barriers, as aligning local strategies with national interests is essential for securing financial support at the national level [26]. Furthermore, analyzing national policies at the local level enables a better understanding of the decentralized nature of energy sources and their optimal utilization [27].

Similar conclusions were drawn from a case study of Hjørring, Denmark [28], which highlighted the need for improved communication channels across different levels of energy planning. The study also emphasized that encouraging local action is feasible if the development of long-term local strategies becomes a mandatory process. This perspective is supported by research conducted in several Danish cities [29–32] where downscaling national strategies to the local level demonstrated that the establishment of smart energy systems, aligned with national strategies, can lead to significant emission reductions. These findings position cities as strongholds of the energy transition and as key actors in achieving national energy goals.

Moreover, the creation of strategic urban energy frameworks can contribute to more rational land and energy use, as well as the development of new policies. By considering all urban potentials and local needs, it is possible to design an optimal energy model [33] that requires minimal investment while delivering maximum impact. The effects of national policies at the local level have also been analyzed in other European countries [6, 7] revealing that successful urban energy planning depends on the alignment of local and national objectives, the integration of energy sectors, and the involvement of all relevant stakeholders. Strengthening understanding, cooperation, and dialogue is a key process in achieving energy transitions, which inherently require time, expertise, and substantial financial investment.

Figure 1. Analyzed Case Studies of Urban Decarbonization

Although the potential for urban decarbonization through the lens of national strategies has been examined in several European cities, these case studies are predominantly located in Western European countries or in countries that are already well advanced in the energy transition process, with clearly defined policy frameworks. As illustrated in Fig. 1, urban energy planning has not yet been extensively explored in the context of cities in the Western Balkans, regions where the energy sector remains heavily reliant on fossil fuels. Furthermore, existing research rarely incorporates methodologies that engage diverse stakeholder perspectives in the process of urban energy transformation. In this regard, the aim of this paper is to establish and implement a clear methodology for urban energy transition that aligns with national frameworks and incorporates the perspectives of all relevant stakeholders residing in the city.

Therefore, the present study offers a significant scientific contribution by:

1) Analyzing the potential and implications of energy transitions in a Western Balkan country where the energy transition is still in its early stages;
2) Providing insight into the capacity of local levels to contribute to the achievement of national energy goals;
3) Enhancing understanding of the most important criteria for implementing renewable energy measures from the perspectives of various stakeholders, including local governments, academia, non-governmental organizations, and citizens;
4) Demonstrating the value of case study analyses, as each city represents a unique energy ecosystem. The results presented in this study contribute to the expansion of the knowledge base and a deeper understanding of urban decarbonization processes.

The case study pertains to Kragujevac, the cultural, administrative, educational, and industrial center of Central Serbia

3. National Context and Energy Policies

At the European Union level, decarbonization has been driven by the development of energy policies and new strategic frameworks that define priorities and ensure energy security. The overarching energy strategy, known as the *European Green Deal* [34], was introduced with the goal of making Europe the first climate-neutral continent by 2050. Equally important on this path are the regulatory packages *Clean Energy for All Europeans* [35], adopted in 2019, and *Fit for 55* [36], which came into force in 2021. These directives and legislative frameworks regulate the decentralization, democratization, and decarbonization of the energy sector.

As a member of the Energy Community [37], an international organization aimed at creating an integrated energy market, Serbia is obligated to align legal framework with the energy legal frameworks of the European Union. As a result, in August 2024, Serbia adopted Integrated National Energy and Climate Plan (NECP) for the period up to 2030, with a vision extending to 2050 [38]. Additionally, in July 2024, the Draft Energy Sector Development Strategy of the Republic of Serbia up to 2040 with Projections up to 2050 was presented [39]. These documents outline the steps for developing Serbia's energy system, with a focus on increasing the share of RES in the national energy mix.

According to the Law on Energy Efficiency and Rational Use of Energy [40] all local governments in Serbia with more than 20,000 inhabitants are required to adopt Energy Efficiency Programs that promote rational energy use at the local level. In line with this, the city of Kragujevac has published two such programs: one for the period 2018–2022 [41], and another for 2023–2025 [42]. However, the current program is primarily focused on improving energy efficiency in public buildings and includes minimal provisions for the use of RES at the local level.

Due to the absence of additional strategic documents that would guide long-term decarbonization at the city level, further analyses of how national strategies can be adapted and how territorially specific energy potentials can be maximally utilized are of critical importance.

4. Methodology

To determine the impact of the national energy strategy on the decarbonization of the city of Kragujevac, a reference scenario for the year 2019 was first modeled. This scenario serves as a baseline for modeling future energy systems and for comparing the results obtained. The year 2019 was selected because it is the most recent year with available data that is unaffected by the COVID-19 crisis or national-level failures in the electricity sector, both of which led to atypical energy system behavior.

The creation of the city's energy scenario is based on a set of assumptions. Specifically, the city should not be viewed as an isolated energy island, but rather as a part of a broader puzzle that contributes to the achievement of national energy goals. Therefore, it is necessary to establish a connection between the national energy system and the local energy system. In this context, the city should be considered as having a share in centralized energy production systems, as well as in energy demands within nationally significant sectors. In the case of Serbia, centralized electricity production systems include thermal power plants and hydropower plants. Their shares, both in terms of energy produced and primary energy consumed, are determined based on the proportion of the city's population relative to the total population of Serbia[1]. Similarly, the energy demands of the industrial and transport sectors were defined based on the 2019 Energy Balance of the Republic of Serbia [43]. Since the products of the industrial sector are not consumed solely within the cities where they are physically produced, the principle of fairness was established through an even distribution of energy consumption in proportion to the population share of the analyzed city. The same fairness principle was applied to the transport sector, as it is expected that residents travel beyond the geographical boundaries of the city itself. This approach enables a fair distribution of emissions from centralized emitters whose products are used across the entire country and beyond its borders. Consequently, by applying this approach, all cities are given an equal opportunity to achieve climate neutrality, which should be viewed as a national objective.

In contrast, data on energy consumption in the district heating system, as well as the energy demands of all public buildings and public lighting, reflect actual consumption in the city during the analyzed year. Since precise data on heating systems in individual households are not available, statistical data were adopted [44], while data on natural gas consumption in the residential sector were obtained through direct communication with employees of the public enterprise "Srbijagas."

Future energy scenarios are based on the same principles of energy-fair distribution at the city level, incorporating scaled projections of the expected population [45] for the year 2045. The energy model assessing the impact of the ambitious scenario from the Energy Sector Development Strategy of the Republic of Serbia up to 2040 with Projections up to 2050[2] on the city of Kragujevac (Scenario 1) was developed by downscaling national decarbonization measures to the local level, adopting appropriate shares of proposed measures that are feasible within the analyzed locality. Accordingly,

[1] Due to territorial specificities and the fact that existing renewable energy sources (RES) are decentralized systems, the methodology does not include an analysis of their share.

[2] Although the Energy Development Strategy of the Republic of Serbia, as well as the NECP, includes a scenario based on the production and use of nuclear energy, this scenario is not analyzed in this study, as nuclear energy relies on the construction of centralized systems. At the same time, this paper highlights the potential for decentralizing Serbia's electricity system and leveraging the local specificities of cities.

compared to the reference model, the following changes in the energy system are expected under Scenario 1:

1) Increased electricity demand across all sectors, with the potential for demand-side flexibility of up to 25% ;
2) Improved energy efficiency in the building sector, with an annual increase of 1% until 2030 and 2% annually from 2030 to 2045 for the residential sector, and 3% annually until 2030 and 6% annually thereafter for the public building sector from the moment of adaptation of NECP;
3) Increased share of heat pumps, covering 15% of thermal energy demands in households and 25% in public buildings. In individual heating systems, heat pumps replace individual heating systems using fuel oil and coal, and 50% of those using natural gas and biomass;
4) Increased share of electric vehicles. Electricity demand for transport is based on the projected energy demands outlined in the Energy Sector Development Strategy (Table A.11, p. 111 [39]);
5) Introduction of electrolysis processes for hydrogen production and use, based on the demands defined in the model's energy balance;
6) In households, 5% of sanitary hot water (SHW) will be heated using solar thermal collectors;
7) Solar thermal collectors will also be used in the district heating system, according to the projected share;
8) Capacities and production of RES are determined based on the potential for utilizing territorially available RES;
9) Given the planned construction of the Bistrica pumped-storage hydropower plant, the city's proportional share is included to support balancing of installed RES capacity;
10) The demand for biofuels is adopted based on Table A.11 of the energy balance presented on page 101 of the Energy Sector Development Strategy of the Republic of Serbia [39]. It is noted that biomass use is limited to the amount representing the energy potential of biomass in the city of Kragujevac. This decision is justified by the fact that this amount is lower than the globally sustainable threshold for biomass use in the energy sector (27 GJ per capita annually) [30, 46, 47].

Compared to Scenario 1, Scenario 2 of the future energy system of the city of Kragujevac explores the potential for adopting new measures tailored to the city's territorial specificities, measures that are either not included in the Energy Sector Development Strategy of the Republic of Serbia or are more ambitious than those proposed in the Strategy. Accordingly, the following additional improvements are expected in Scenario 2:

1) Renovation of all residential buildings to meet the energy performance level defined by the national regulation for existing buildings (75 kWhm-2) [48]. This level of improvement is based on the assumption that newly constructed buildings during the analyzed period will consume significantly less energy, allowing for a lower efficiency threshold in existing buildings. Previous studies have shown that achieving climate neutrality by 2050 is possible if 90% of buildings undergo deep renovation (up to 90% energy savings) [49];

2) Installed PV panel capacity is determined based on the technical rooftop potential, assuming that all households will become prosumers with 5 kW systems, and all existing factories in the industrial zone will install 150 kW systems, in line with current regulatory limits. PV capacity on public buildings is based on rooftop surface area analysis;
3) A portion of centralized district heating units will be upgraded with combined heat and power (CHP) technologies;
4) Excess heat from the city's data center will be utilized in the district heating system;
5) Construction of a waste incineration plant is proposed for combined heat and power generation, with future projections accounting for increased plastic waste recycling;
6) Seasonal thermal energy storage will be integrated into the district heating system;
7) Waste heat from electrolysis and gasification processes will be used in the district heating system;
8) Biomass will be gasified in accordance with the city's total local biomass potential;
9) An additional 18% increase in heat pump capacity in individual households is expected compared to Scenario 1.

Essentially, Scenario 2 investigates the potential for fuel diversification in the district heating system. Exploring such options is important, as they can improve the reliability and independence of the heating system, potentially leading to optimized production costs [50].

Although the Energy Sector Development Strategy of the Republic of Serbia envisions the use of solar thermal collectors in district heating systems, in Kragujevac, SHW is most commonly heated using individual electric heaters, even in households connected to the district heating system. It is therefore concluded that the application of solar collectors in Kragujevac's district heating system is not justified, as there is no heat demand during the summer months when solar energy potential is highest.

Scenario 3 thus explores the possibility of expanding district heating system capacity to include SHW heating. The demand for thermal energy during the summer months within the district heating system can enablegreater integration of excess heat, RES (particularly PV panels, whose electricity generation is most pronounced during summer period) and heat pumps into the district heating system, due to the presence of a year-round base load.

All three scenarios refer to the year 2045, the year for the energy balance presented in the Energy Strategy of the Republic of Serbia. To facilitate comparison, Tab. 1 presents the total population of Serbia and the population of the city of Kragujevac for the reference year, as well as the projected population for the scenario year, 2045.

Table 1. Population in Republic of Serbia and City of Kragujevac for 2019. and 2045.

	Referent year (2019)	*Projected population for Scenarios Year (2045)*
Republic of Serbia	6,647,003	5,450,542
City of Kragujevac (Urban part)	146,315	127,587

All scenarios were modeled using the EnergyPLAN software [51], which enables comprehensive energy system analysis through the integration of all energy sectors. The validity of this tool is supported by its use in over 315 academic studies since 2021, across various scales, from national to city-level systems [52].

Since each scenario results in different socio-technical and economic parameters, a multi-criteria decision making (MCDM) combined with stakeholder opinion assessment was used to determine the most suitable pathway for the city's decarbonization process (Equation 1). Various methods can be applied in decision-making processes within multi-criteria analysis. For the purposes of this study, the Weight Sum Method (WSM) is proposed, as its simplicity allows for replication in different case studies and supports greater citizen participation in decision-making. The ranking of proposed measures is based on Equation 1:

$$Ri = \sum_{i=1}^{n} k_j \cdot \overline{n_{ij}} \quad \text{for } i=1 \text{ to } m \tag{1}$$

Where:

R_i [−] The result of the WSM method; a higher score indicates a higher priority in the ranking;

n [−] Number of criteria;

m [−] The number of proposed RES measures;

k_j [%] weight factor for each of the criteria;

n_{ij} [−] normalized factor for each proposed measure;

The normalized factor for each measure was determined based on whether the optimal result for a given criterion is the highest or lowest value within the range of simulation results. For criteria where lower values are more desirable, the normalized value n_{ij} is calculated as the ratio between the minimum value among all proposed measures and the value obtained for the observed measure. For criteria where higher values are more desirable, the normalized value nij is calculated as the ratio between the value obtained for the observed measure and the maximum value among all proposed measures within the given criterion.

In total, six criteria were considered,, divided into three categories: Techno-economic (annual amount of energy produced/saved, installation costs, and maintenance costs); Social (job creation during construction and job creation during operation of technologies); Environmental (CO_2 emission reduction). The implementation costs were adopted based on the planned budget for each measure presented in the NECP[3], while maintenance costs were calculated as a percentage of investment costs, in accordance with the recommendations of the Danish Energy Agency and their projections of future prices [53]. Data on job creation were taken from a comprehensive study [54], while data on energy savings/production and CO_2 emissions were obtained through simulation of the energy model.

Weighting factors were determined by conducting a survey among local stakeholders, including representatives from academia, non-governmental organizations, local decision-makers, and citizens, who evaluated the importance of the proposed criteria based on their personal preferences.

The methodology used in this study is schematically presented in Fig. 2.

[3] The authors of the paper mention that the investment costs presented in this document are significantly higher than the expected values compared to the anticipated investments shown in the Technology Catalogue [53], which was created based on expected market changes in Denmark.

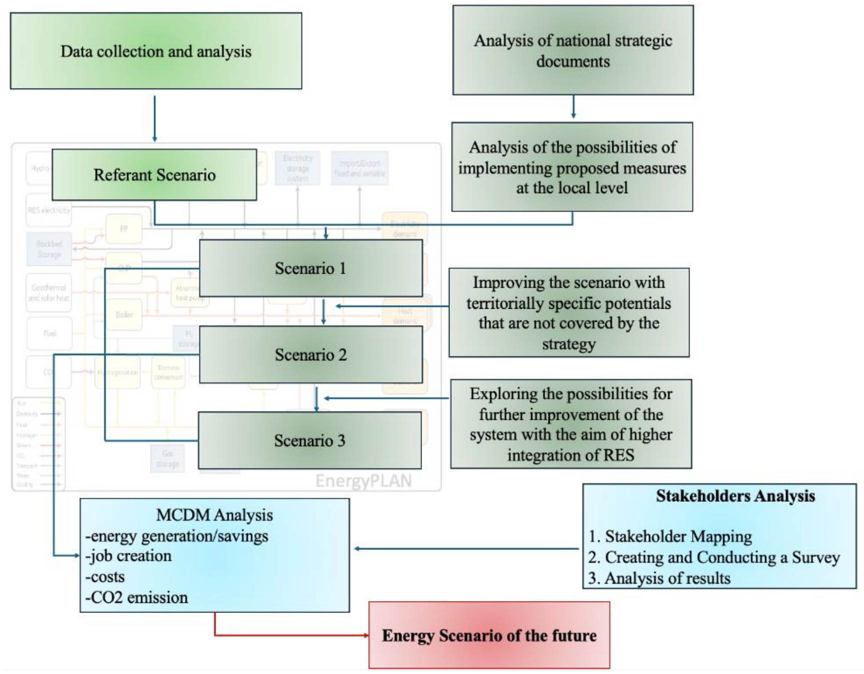

Figure 2. Methodology Used in the Study

5. Results and Discussion

The results of the energy modeling for the Reference Scenario, presented in the flow diagram (Fig. 3), indicate that energy supply in Kragujevac is still highly dependent on the use of fossil fuels, accounting for 79% of total primary energy consumption.

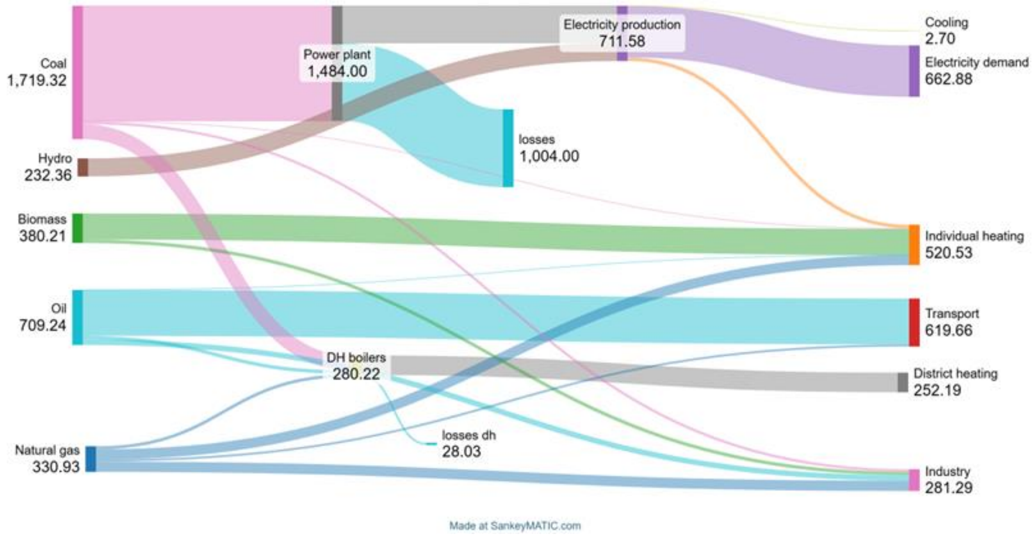

Figure 3. Energy Flow Diagram (in GWh) of the Reference Energy Model for the City of Kragujevac for 2019

Since electricity in Serbia is predominantly produced in centralized, low-efficiency thermal power plants (estimated efficiency 33%), coal holds a significant share in the energy mix (51% at the level of the city of Kragujevac). Fossil fuels are also widely used in the transport sector (primarily oil) and in industry (natural gas, coal, and oil). The current energy mix includes a certain share of RES, mainly hydropower (7%- centralized electricity production systems at the national level,) and biomass (11%). However, as shown in the diagram, biomass is mostly used in individual heating systems with low efficiency, and therefore its use cannot be considered sustainable. The reference energy system of the city of Kragujevac results in emissions of 847,84 $ktCO_2$. The adoption of measures from the Energy Sector Development Strategy leads to changes in the city's energy system and energy behavior. As shown in Figure 4, Scenario 1 results in a significant reduction in the use of coal and oil. Yet, a notable increase in the use of natural gas is expected in this system. Due to local geographic constraints, wind power plants cannot be installed in Kragujevac, so the increase in RES share comes from the installation of PV panels, with an expected annual production of 246 GWh. Additionally, improvements in the efficiency of existing hydropower capacities and the construction of new ones at the national level are anticipated. Furthermore, Scenario 1 introduces changes in the transport sector, with a reduction in the use of oil by 190 GWh (33%) and natural gas by 26 GWh per year (95%), along with the introduction of biofuels (12 GWh annually) and hydrogen (96 GWh annually) into the energy mix. At the same time, the use of coal and oil in individual heating systems is completely phased out, while the use of natural gas is reduced by 87 GWh (67%) and biomass by 190 GWh annually (56%), with increased adoption of heat pumps.

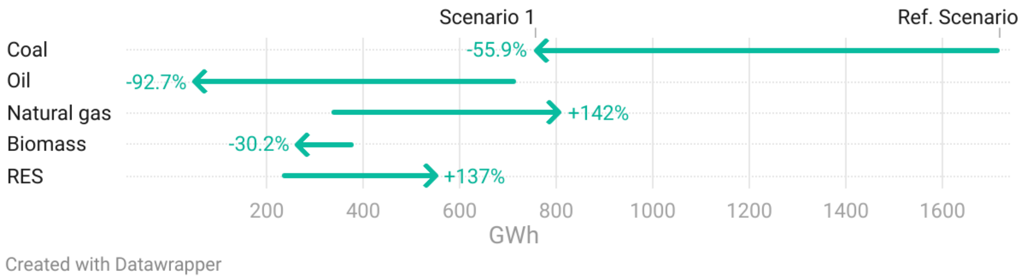

Figure 4. Changes in Annual Energy Use (GWh/year) in Scenario 1 Compared to the Reference Scenario

All these changes result in a reduction of carbon dioxide emissions by 284 $ktCO_2$ on yearly level (33%).

Analyzing the local characteristics of the city of Kragujevac, it was determined that, in addition to the measures proposed in the strategy, the city has the potential to implement additional actions that could further contribute to the decarbonization process. Since waste disposal has long been a significant issue in the city, Scenario 2 proposes the construction of a waste incineration plant. Additionally, the city hosts a data center that requires continuous cooling of electronic units. This excess heat can be utilized in district heating systems through the use of heat pumps. As a new residential block is expected to be built near the data center, the generated excess heat can be used locally, thereby reducing losses. Scenario 2 also includes a significant increase in energy efficiency and solar panel deployment, contributing to the decarbonization of the existing energy system, with a total emission reduction of 436 $ktCO_2$/year.

Since variable RES primarily involve PV panels, whose production peaks during summer months, and given that the city's district heating system is not currently used for SHW heating, Scenario 3 explores the possibility of upgrading the district heating system. This approach not only increases the integration of RES (from 27% in Scenario 1, to 37.8% in Scenario 2, and 39.8% in total energy consumptionin Scenario 3 compared to the Reference Model), but also improves the utilization of installed heat pump capacities within the district heating system. This can be explained by the fact that energy storage within the district heating system enables the maximization of renewable energy utilization at the time of its generation. Specifically, the system will use the produced energy when it is available, while the storage component will allow its application when it is needed. Expanding the district heating system to include SHW provision facilitates further exploitation of waste heat potential and reduces reliance on centralized energy systems for electricity generation used in SHW heating processes.

A comparison of all the mentioned scenarios and the reference model is presented in fig. 5.

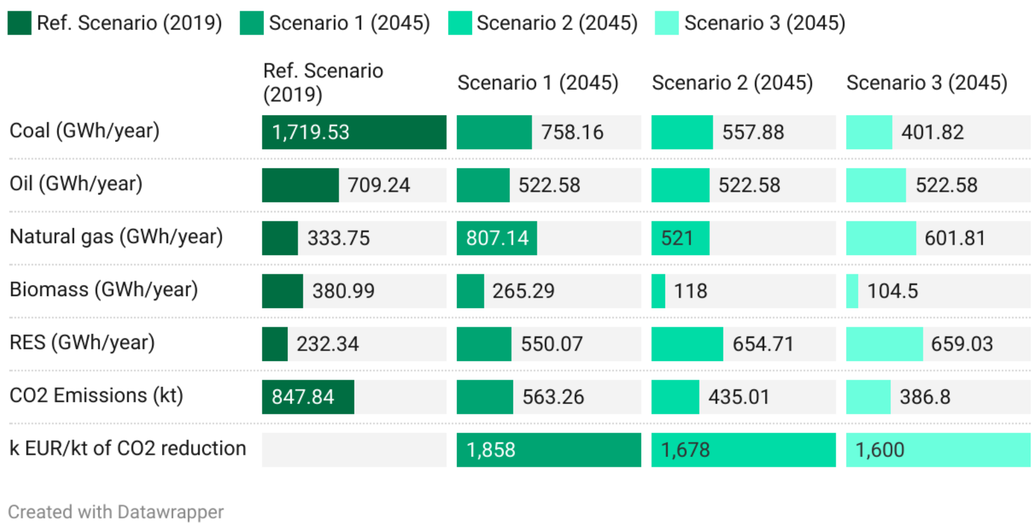

Figure 5. Comparative Overview of the Results of Future Scenario Analysis for the City of Kragujevac (annualy consumption and emission)

All analyzed scenarios result not only in the presented techno-economic changes but also in certain social developments, such as the creation of new jobs. The impacts of the analyzed scenarios on the mentioned criteria are presented in Tab. 2. As can be observed from the data in Table 1 and Figure 5, Scenario 1 requires the lowest financial investment, but also results in the smallest reduction in CO_2 emissions. On the other hand, although it requires a higher initial investment and more expensive system maintenance, Scenario 3 leads to a more significant reduction in CO_2 emissions, as well as greater energy savings and production. Also, total cost per kt of CO2 reduction is highest in Scenario 1 and lowest in Scenario3.

Table 2. Impacts of Future Energy Scenarios on Techno-Economic and Social Aspects until 2045

	New jobs (construction)	New jobs (O&M)	O&M costs (kEUR annually)	Investment costs (MEUR)
Scenario 1	6,236	288	3,217	530,761
Scenario 2	9,119	414	5,516	692,588
Scenario 3	9,119	414	5,516	737,714

Accordingly, the decision regarding the future scenario for the city of Kragujevac was made based on stakeholder input. Citizens, employees from academia, local government, and non-governmental organizations were asked to evaluate the importance of various criteria in the transition to sustainable energy systems. The survey was completed by 127 residents of Kragujevac, and the results are summarized in Fig. 6. It is evident that energy production/savings is considered the most important criterion, while job creation was rated as the least important across all surveyed categories.

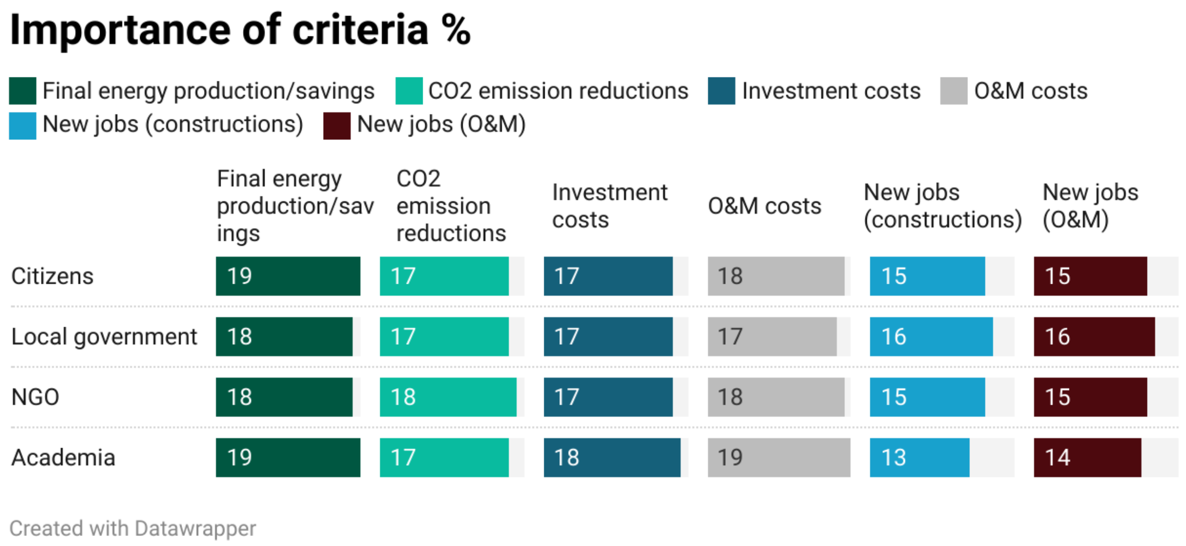

Figure 6. Public Opinion Survey Results on the Importance of Criteria Related to Renewable Energy Integration Measures

By normalizing the collected data and applying MCDM (Eq. (1)), it was determined that Scenario 3 ranks highest among the proposed scenarios (Tab. 3.).

Table 3. Ranking of the Scenarios applying MCDM

	GWh produced/saved energy	*Investment cost (MEUR)*	*CO2 reduction (ktoe)*	*New job-construction*	*New job O&M*	*SUM*	***RANK***
Scenario 1	0,027	0,178	0,074	0,107	0,105	0,491	**3**
Scenario 2	0,169	0,136	0,150	0,157	0,151	0,763	**2**
Scenario 3	0,188	0,128	0,177	0,157	0,151	0,801	**1**

The energy flow diagram shown in Figure 7 reveals that Scenario 3 involves significant utilization of Kragujevac's solar energy potential, generating an amount of energy that meets nearly one-third of the city's energy demands. At the same time, this scenario includes the use of surplus energy for hydrogen production. Additionally, the use of excess heat from industry, production processes, and the data center reduces the need for fossil fuels in the district heating system. However, despite being more ambitious than the already ambitious scenario presented in the Energy Sector Development Strategy of the Republic of Serbia (as well as in the NECP), it is evident that this scenario still relies on the use of fossil fuels-particularly in the industrial, transport, and electricity production sectors.

During the analyses conducted in this study, the use of carbon capture and storage (CCS) technologies, as well as the implementation of next-generation electro fuel production technologies, was not taken into consideration, as these technologies are only briefly mentioned in the relevant strategic documents. Based on this, it can be concluded that they are not part of the country's established policy objectives. However, if carbon emission costs are taken into account—projected to reach €500 per ton of CO_2 by the year 2044 [55][4], An additional cost of €194.5 million can be expected under Scenario 3. For comparison, the projected carbon tax costs in Scenario 1 amount to €285 million in the year 2045. Therefore, although Scenario 3 entails higher investment expenditures, it results in a long-term reduction in annual emission-related costs, while simultaneously improving the market positioning of products from the Republic of Serbia. Accordingly, this study proposes the establishment of a national fund, modeled after the carbon offsetting concept [56] which would support the development of decarbonization projects in energy-intensive sectors, particularly in locations where their implementation is most justified. Furthermore, this fund could contribute to the advancement of science and technological development in the fields of energy, renewable energy sources, carbon capture and storage, and e-fuel synthesis.

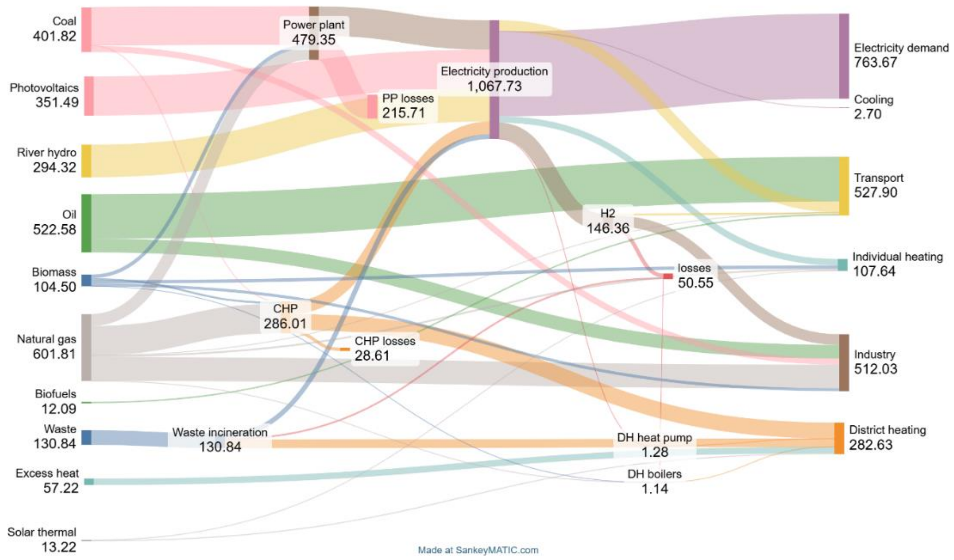

Figure 7. Diagram of energy flows (GWh) in the proposed energy scenario for the city of Kragujevac for the year 2045

6. Conclusion

As the onset of climate neutrality in cities should be grounded in national energy objectives, this study demonstrates that national energy strategies, although formulated at a high level, can be adapted to local specificities by taking into account the technical, economic, and social characteristics of local communities. Through a case study of the city of Kragujevac, three scenarios for the development of

[4] Although the carbon tax price is expected to remain stable at 70 EUR/tCO_2 between 2025 and 2030, a significant increase is anticipated after this period.

local energy strategy were analyzed, each offering a different ambition, and the degree of integration of local potentials. A MCDM involving various stakeholder groups, was conducted to identify and evaluate the key criteria recognized by the local community as important in the energy transition process. The highest priority was given to measures that contribute to energy savings and production. Conversely, criteria such as job creation were deemed less important, which may indicate a need for further awareness-raising and education on the broader socio-economic benefits of the (just) energy transition.The results indicate that the scenario which extends national strategy measures to include the utilization of specific local potentials not covered by the strategy was ranked highest and best aligns with the needs and expectations of the local community. This scenario not only contributes to emission reductions and improved energy efficiency but also lays the foundation for a long-term sustainable energy system at the local level. Although the study did not include the production of next-generation electro fuels, it identified the need for a systematic national-level approach to this issue. The authors propose the establishment of a national fund to support the development of projects in locations with the greatest potential and need, such as cities with high emissions and industrially intensive areas. This initiative could represent an important step toward the decentralization of energy policy and more efficient resource utilization, while also contributing to the advancement of science and the development of national research and innovation projects. Future research should focus on developing mechanisms for institutional support to local communities, as well as on the integration of new technologies and energy sources into local energy systems.

Nomenclature

R_i [−] The result of the WSM method; a higher score indicates a higher priority in the ranking;
n [−] Number of criteria;
m [−] The number of proposed RES measures;
k_j [%] weight factor for each of the criteria;
n_{ij} [−] normalized factor for each proposed measure;

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