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REVIEW ARTICLE

Facilitating circularity in city governance in the Republic of Serbia: a novel approach to modeling of energy efficiency big data mining

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Abstract Efficient use of energy and other resources, as the basic postulates of the circular economy, is a prerequisite for the green transition to more sustainable cities in the future. The main scientific goal of the paper is the development of a new approach to city governance when it comes to the inefficient use of energy, predominantly fossil fuels, mainly in developing and poor countries. Energy efficiency problems faced by these countries require the introduction of urgent, applicable, and realistically achievable solutions. A prerequisite for adequate analysis and modeling of energy efficiency performance, measures, policies, outcomes, and impacts is the introduction and functioning of the big data management system, which should begin with data mining. On the other hand, adequate data collection has been neglected in many of these countries. The study shows a way to reduce this gap, but in accordance with realistic and limited possibilities for countries with less favorable conditions. In that respect, a conceptual model for the ***Analytical Service for facilitating energy efficiency in city governance*** was developed and presented as a driver that can enable cities to manage energy more efficiently. The model is based on an interdisciplinary approach and on the needs of cities in the Republic of Serbia. However, it is designed to allow upgrading in accordance with the capabilities and resources of cities, primarily applicable in developing and poor countries.

Keywords Energy efficiency · City governance · Conceptual model · Data mining · Republic of Serbia

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Introduction

Modern cities have been developed on a traditional, linear way of using resources (Islam, 2011). Due to the influx of inhabitants, cities have expanded, while resilience and sustainability have just recently been brought into consideration (Sharifi & Yamagata, 2018). Urban areas represent a major source of environmental pollution (Pasqua et al., 2018) and, at the same time, are very susceptible to the risk of natural and industrial disasters (Pelling, 2013). Due to industrialization and increased traffic, cities face the problem of climate change (Mi et al., 2019), and due to

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high population density, the damages caused by climate change are extremely large (Sajjad et al., 2021). In consideration of all of the above, solutions and approaches are being sought to facilitate the development of resilient and sustainable cities for current and future generations. The above represents a complex undertaking because cities are located in different geographical and climatic regions, in countries at different levels of development (Kazemi, 2022), and with complex migratory movements that are conditioned by a large number of factors (Bonakdar & Audirac, 2020).

A special source of urban risk in modern urban areas is environmental pollution, which is largely caused by the use of energy (Xu & Xu, 2022; Elavarasan et al., 2022) and leads to large-scale emissions of greenhouse gases (Nie et al., 2022). Sustainable urban planning is essentially based on the sustainable use of resources, environmental preservation, and pollution reduction, i.e., the application of circular economy principles aimed at creating the conditions for a better quality of life for inhabitants (Mersal, 2016). Over time, a number of approaches based on different assumptions and expectations have been developed for future urban planning (Barnett, 2016), and there is no universal approach to sustainable urban planning. A comprehensive study conducted in 2017, which included the analysis of 102 studies, revealed that it is not possible to properly define common priorities or map them to other inhabited areas (Geneletti et al., 2017). This leads to the conclusion that there is a need for further analyses and the development of solutions at the local level in relation to the principle of demand and supply performance (Cortanovis & Geneletti, 2020), while respecting the principle of heterogeneity (Pan & Wang, 2021).

Incorporating the principle of circularity into urban planning opens up a wide range of possibilities to solve the growing problem of sustainable urban planning in a certain segment and with a certain capacity (Remøy et al., 2019). In its essence, circularity represents the concept of efficient use of natural resources and reduction of waste generation, bringing it closer to nature-based collusions (Xie et al., 2023). Therefore, circularity can be considered one of the very effective approaches to sustainable development of cities and society as a whole, as demonstrated by examples of big cities like Melbourne in Australia, Malmö in Sweden (Bolger & Doyon, 2019), Brussels in Belgium (Kębłowski et al., 2020), London in the UK (Williams, 2022), and Helsinki in Finland (Hu et al., 2021). Based on those examples, it can be concluded that circular urban development produces cities that use resources efficiently, with reduced pollution and greater resilience (Williams, 2023).

A review of the literature identified the two biggest challenges faced by circular urban area design—energy efficiency and urban area governance, with transport and housing being the main sectors and flows (Lucertini & Musco, 2022; Cárdenas et al., 2021). Circular economy has great potential in the process of improving energy efficiency and decarbonization in general, but the existing energy systems generally ignore or inadequately present and monitor circular economy measures (Panagiotis, 2022; Taifouris & Martin, 2023). Resilient, circular, and sustainable urban planning is a practice that has been started in a certain number of cities and regions, but for now, it is reserved exclusively for countries that meet three basic prerequisites: a higher level of economic development, adequate regulation, and efficient governance (Fratini et al., 2019). The inclusion of the principle of circularity in urban planning is mostly applied in the Scandinavian countries (Colasante et al., 2022), where practice shows that the application of an individual approach, adapted to each city, is imposed as a prerequisite for finding solutions for resilient urban planning. Therefore, the aforementioned is used as a starting point for the preparation of this study.

Considering all the above, the necessity to find a way to integrate circular economy, energy management and efficiency measures in different sectors, including in urban planning, is evident (Seljak et al., 2023). This paper represents an attempt to lay the first methodological basis for facilitating circularity in urban governance in the Republic of Serbia, tackling one of the main priorities -– a new approach to energy efficiency management for cities. In order to define an adequate energy efficiency management approach for cities, cooperation with the academic community is necessary, however, in Serbia it is sporadic, unplanned, unsystematic, and therefore inadequate (Milovanović Rodić et al., 2018). In that respect, the ***Analytical Service*** proposal presented in this paper can be considered a contribution of the academic community, derived from researchers' work, rather than an actual need expressed by urban area management bodies in the Republic of Serbia.

Republic of Serbia—key urban energy features

The Republic of Serbia adopted the Sustainable and Integrated Urban Development Strategy until 2030, but its implementation is hampered or impossible due to various factors. Therefore, increasing resilience and applying circularity design is still at the level of theoretical knowledge, and the need exists for further education and the creation of realistic prerequisites for application in practice (Maruna et al., 2018; Gibellato et al., 2023). The Republic of Serbia has certain features that are important for the possible application of circularity in urban planning. First, electricity is produced predominantly from lignite, exploitation is carried out in the immediate vicinity of large cities with high emissions of harmful gases and heavy metals and energy intensity is exceptionally high (Ćujić et al., 2017). Agricultural production is affected by chemical agents, and industrial plants are located in the immediate vicinity of populated areas, all of which cause pollution of air, soil, and watercourses. The Republic of Serbia is exposed to natural disasters (earthquakes, floods, and landslides) with significantly harmful consequences (Stanković et al., 2020). It is also exposed to industrial disasters, primarily due to the application of old technologies and coal exploitation, with no warning-response-rehabilitation system developed.

Decades of migration from villages to cities have resulted in large cities being overpopulated, while some areas of the country are nearly deserted (Kupiszewski et al., 2012). There are big differences between cities in terms of economic activity, population structure, infrastructural equipment, and the like. The population and industry generate large amounts of waste that are disposed of in landfills, of which only 11 are sanitary but where only about 20% of waste is disposed of, leaving the problem of hazardous waste unaddressed (Ilić & Nikolić, 2016). Monitoring of indicators of importance for environmental and climate change risk assessment is non-transparent (Knez et al., 2022) or even non-existent (Podbregar et al., 2020). In addition, urban planning is hampered by the fact that a large portion of real estate in the Republic of Serbia has not been legalized, and the legalization process is very slow. Due to this situation, there are entire illegally built settlements with no urban planning conducted and with tens of thousands of inhabitants, some of which are located on or near landslides (Lukić et al., 2018). Privatization of urban land continues without respecting its purpose (Bedović-Budić et al., 2012) and it is dominated by the construction of large housing developments and roads that will further burden the already fragile environment. The lack of adequate regulation on flood prevention is a particular problem because numerous unregulated watercourses are located near settlements or flow through cities, thus posing a high risk and danger (Nikolić Popadić, 2021). During the 1990s, an extremely large number of housing units were transferred from state to private ownership without an adequate strategy for further urban planning (Nedučin et al., 2021), and due to the poor social situation, the new owners are generally unable to maintain their apartments in a way that would facilitate the efficient use of energy. The Republic of Serbia provides incentives for improving energy efficiency, but the response of citizens is minimal (Jednak et al., 2020).

Fossil fuels are predominantly used in transport, means of transport are old, and collective transport is poorly developed, which altogether leads to inefficient use of energy in transport, high pollution (Jovic Vranes et al., 2018), daily traffic congestion, and a very high degree of noise (Prascevic et al., 2014). Energy efficiency in buildings is generally at an unsatisfactory level (Staniaszek, 2019). Electricity, fossil fuels, and various types of waste are mainly used for city heating in the Republic of Serbia, where only about 10% of households are connected to the district heating system. About 60% of the electricity needs are sourced from the operation of coal-fired thermal power plants, and the remaining 40% is from the operation of large hydropower plants (Stamenić et al., 2016). The degree of pollution caused by the exploitation of coal is very high, and this has been a problem for the Republic of Serbia for decades. Comparatively low electricity prices, transmission losses, citizens limited financial means that could be utilized to finance improvements in energy efficiency and inefficient consumer habits (Filipović & Tanić, 2010) are the fundamental hindrances to a more meaningful change in the field of energy, including the introduction of circularity.

On the other hand, measures to improve energy efficiency in cities in the Republic of Serbia are sporadic, mostly one-off, and lack intersectoral cooperation and adequate monitoring. Cities in the Republic of Serbia have not developed mechanisms or modern analytical instruments to effectively manage energy efficiency, and as a result, they are incapable of planning and implementing measures and monitoring the effectiveness of implementation thereof.

Material and methods

Methodological settings

Bearing in mind the insufficient volume of research on facilitating energy efficiency as one of the pillars of circularity in urban planning in the Republic of Serbia, the research represents a unique challenge. Due to the non-transparency of data on pollution, climate change indicators, and the generation of waste, it is not possible to conduct research based on reliable empirical data. That is why the authors, when researching, primarily rely on the overview of previous research as examples from practice while respecting the geographical, demographic, economic, ecological, and governance-related specificities in the Republic of Serbia.

The literature search uncovered a wealth of intensively developed solutions for smart city applications and services, all recommending the development of data management systems and other smart city solutions to align with city specificities. Thus, the analysis of the *Internet of Things* can be used for the analysis of large-scale data, with the application of resource allocation schemes, offloading, and similar systems to support analytical services (He et al., 2018). In addition, there are big data management solutions for city needs that rely on a *cloud-based service* (Khan et al., 2015). Research is also based on the development of a taxonomy for data entities, data production, and data analytics since there are different approaches for the aforementioned (Moustaka et al., 2017). However, it should also be noted that solutions based on the application of artificial intelligence are increasingly being developed with the advancement of technology (Jahan et al., 2022). The research on the development of smart city applications, as proposed in this paper, involves data management based on data gathering but relying on the application of *fog-based data analytics* (Lata & Kumar, 2022). In addition, a *Hadoop-based* prototype implementation that has also been developed (Osman, 2019) clearly notes that further research in this field is indeed needed, but that it is first necessary to clearly define the environment for which a certain smart application is to be developed.

Figure 1 describes the complexity of the domain under study. Local government (LG), academic community (AC), non-governmental organizations (NGOs), and citizens should participate in the planning and implementation of numerous activities aimed at increasing energy efficiency at the local community level. In addition to budgetary resources,

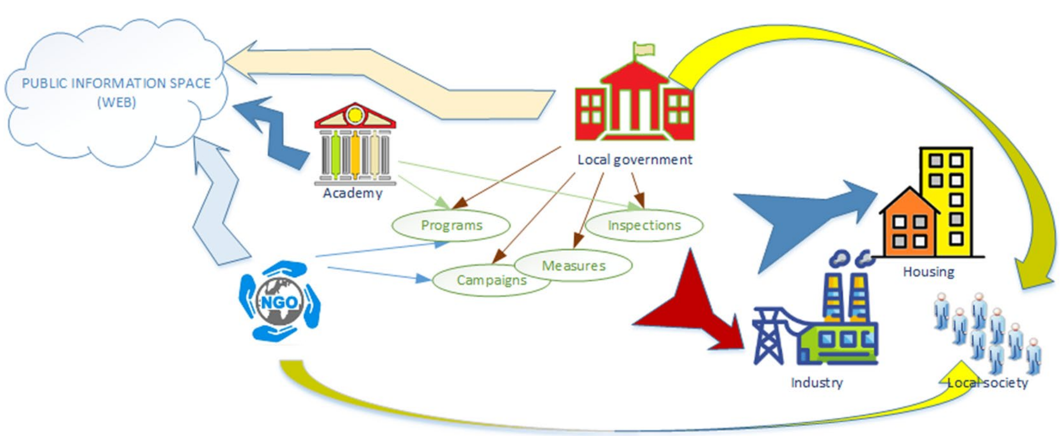

Fig. 1 Stakeholders involved in urban planning for energy efficiency: domain of expertise complexity

dedicated EU funding and funds from other sources are allocated for programs and campaigns aimed at increasing the energy efficiency of economic entities and housing. However, there is no strong coupling and synergy between the aforementioned entities in the Republic of Serbia that could make planning, measures taken, and implementation control efficient. On the other hand, all four entities (LG, AC, NGOs, and citizens) usually plan and implement certain activities independently of each other and publish the respective results through different communication channels. The above also represents the end of the process of implementing a specific activity without further analysis.

The implementation of activities to improve energy efficiency is associated with a large number of problems. The lack of analytical public services at the level of local self-government units poses a crucial problem, as it hinders the establishment of a unique and standardized method for information gathering, data processing, and reporting that aligns with local urban planning needs. In order to obtain the data, it is necessary to analyze heterogeneous sources of content presented in a different format. Therefore, the paper proposes a hybrid system that allows for the collection of relevant content, the extraction of useful information, the statistical processing and analysis, and finally, the interpretation and use thereof. The previous illustration and its description depict the structural complexity of the research problem. This is not adequate, given that energy consumption varies dynamically in the time dimension—intervals, among which the periods of the day (periods of lower/higher tariffs), days of the week (working days, weekends), weeks of the year, months, and quarters (seasons) stand out. For this reason, the assessment of energy efficiency cannot be complete without the analysis of different time series of data, which introduces additional complexity in system modeling.

Starting from the fact that, globally, research results show that cities consume about 75% of natural resources, emit about 70% of greenhouse gases, and generate about 50% of waste (Balletto et al., 2022), solutions must be sought first in the direction of energy efficiency improvement in order to reduce pollution through the reduction in energy consumption.

The transition to energy-efficient and resilient urban planning in the Republic of Serbia is a complex process associated with a large number of challenges that can be divided into economic, social, environmental, and governance-oriented. Urban planning requires the analysis of a large number of factors that are frequently poorly defined and whose interconnections are not always well understood. Moreover, urban planning is a dynamic process that should respond to modern society's demands, with all the changes and challenges brought about by environmental changes. If the above is missed and the urban planning process is not reviewed and adjusted, cities rapidly become unsustainable, quality of life declines, and numerous social, economic, security, logistical, and demographic problems emerge.

Considering the above, it is necessary to develop methodologies for urban planning and urban management needs in a way that includes the principles of circularity, sustainability, and resilience. Although it is useful to start with examples from practice, it is still necessary to develop one's own approaches in accordance with the specificities of urban areas. The methodologies mentioned above must be dynamic, adaptable, and able to operate with a large amount of data, as well as respect the ever-present uncertainty and possible volatility (Šimić et al., 2021; Lin et al., 2021). No urban planning, no matter how much it adheres to sustainability or circularity principles, can be considered completely accurate. Therefore, it is crucial to employ methods that consistently account for the potential failure or limited success of an activity. This is especially important in the case of cities and countries that are at the very beginning of resilient urban planning, where pollution caused by inefficient energy consumption has hazardous proportions, which is certainly the case with cities in the Western Balkans region, i.e., in the Republic of Serbia (Radovanović et al., 2022) and in Southeastern Europe (Novikova et al., 2018). Therefore, the development of the initial methodology for facilitating circularity in urban planning, presented in this paper, can be considered a pioneering step.

The establishment of the methodological framework is predicated on the need to explore potential solutions for an exceedingly intricate problem that lacks definitive resolutions in the Republic of Serbia and the surrounding region yet is of utmost importance and urgency. For several decades, the Republic of Serbia has grappled with energy inefficiency in cities (and in general). Compounding the problem is the predominant use of coal and oil as primary energy sources, which results in significant pollution levels in urban areas and sometimes threatens the health of the population.

The resolution of this issue necessitates the implementation of an appropriate energy management strategy, which involves a comprehensive array of measures, activities, and changes across all domains. This endeavor is intricate and requires decades to complete. The process has to be initiated and established, regardless of its complexity, in order to facilitate its implementation in the coming years and achieve incremental improvements in energy efficiency and pollution reduction.

After careful consideration of the aforementioned and in accordance with the principles of scientific research, the methodological framework depicted in Fig. 2 was chosen for the implementation of this research Fig. 3.

The conceptual research method was selected as the fundamental methodological approach, as illustrated in Fig. 2. This method is deemed suitable for research that lacks prior qualitative and quantitative data, which is undoubtedly the case in this research. Furthermore, the problems and the main goal of the research were defined. It is evident that the Republic of Serbia is plagued by a multitude of issues regarding energy efficiency in its cities. However, it is impossible to comprehensively examine and evaluate them in a single study. Therefore, this research concentrates on a single issue that is highly intricate. However, it can be resolved with the assistance of technical prerequisites and a sufficient level of expertise: energy efficiency big data mining.

Fig. 2 The methodological framework

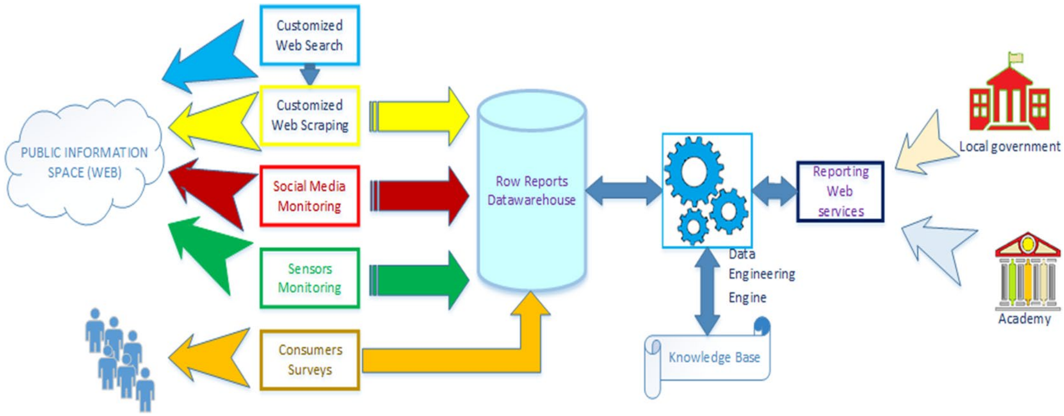

Fig. 3 A Conceptual Framework for an Energy Efficiency Analytics System

Specifically, making decisions aimed at energy efficiency enhancement must be founded on a realistic evaluation of the current state. This necessitates collecting adequately selected data that accurately represents the current state of the system under observation.

The Republic of Serbia opted for sustainable development and accession to the European Union and accordingly defined goals in the domains of energy policy and ecology. However, the extent of the discrepancy between the actual situation and the accepted objectives, as well as the specifics of this discrepancy, remain unknown. As a result of the aforementioned, it is impossible to accurately ascertain the severity of the issue, formulate predictions, or specify the course of action that should result in improvement.

However, in light of the economic issues and the overwhelming global crisis, it is not advisable to make any premature judgments, particularly in the domain of energy policy. Therefore, the study proposes a concept for enhancing energy efficiency that is not predicated on the establishment of a novel energy policy (due to the significant risk of inaccurate assessments, which will have a decade-long impact) but rather on the gradual introduction of modifications that are both feasible and acceptable for the countries confronted with economic, social, and security challenges. Given the aforementioned, it is recommended that a system be implemented to collect and process energy efficiency-related data at the city level, to the extent compatible with the technical and economic capacities of the cities, while meeting the fundamental requirements.

Explorations and advancements in pertinent research

Based on the literature review of the papers published in the last decade in 15 countries (Lim et al., 2018) the developed methodologies indicate high complexity and the need for decomposing big data analytics into several subprocesses. The most important of them are data collection, storage, processing, analysis, and consumption.

Many different sources of information are available to help cities improve energy efficiency. Data collection comprises the readings of numerical values from different types of sensors, networks, and infrastructures, as well as the collections of heterogeneous data from social networks and inquiries:

- Sensors for weather conditions: These sensors obtain data about temperature, humidity, wind speed, sun exposure, atmospheric precipitation, and air pollution. The presented papers point out wireless sensor networks (Trilles et al., 2016) as the infrastructure necessary for centralized data collecting that facilitates big data analytics.
- Traffic sensors: These sensors obtain data about traffic intensity, the throughput of the streets and roads, and traffic bottlenecks produced by traffic jams or incidents. For these purposes, the authors emphasize the importance of sensors installed in light poles (Bermudez-Edo et al., 2018).

- Internet of Things (IoT) infrastructures (Fotiou et al., 2018): These are primarily implemented in residential buildings, public buildings, and industrial facilities; they include smart devices that read the status from one or more sensors, collect and pack the data about heating, cooling, lighting, and energy consumption, and emit them periodically (e.g., from several seconds to several minutes) to the remote data storage servers through the Internet connection.
- Mobile networks: They can provide data about time (daily) changes in population density and population mobility in urban areas (Yao et al., 2021); collected data about the mobility of people is related to the traffic data explained above and can be correlated with them.
- Social media networks: They represent an important source of informal information related to energy efficiency. People attempt to share information about actual problems, expressing their attitudes about them and offering solutions; social media data is challengeable for analysis as it lacks specific and predefined structure and format; besides the informal text, it frequently includes multimedia content and commenting with emoticons (Stieglitz et al., 2018).
- Surveys: They represent the traditional and formal way of collecting information about targeted topics. Owing to contemporary technologies (SMS and web-based surveys), the survey still represents a useful technique for information collection Alam et al., 2014). For instance, the survey can gather public opinion about future investments in energy efficiency and the actual state and priorities in this matter.

Regarding their origin, collected data have a different structure, format, and type of content. For instance, there are time series and geospatial data, but there are also data that cannot be put in these two dimensions, such as data from surveys and social media. Therefore, cloud storage represents the appropriate solution for collected data storage (Goel et al., 2020). In cloud-based storage solutions such as Mongo Atlas (https://www.mongodb.com/atlas/database), Microsoft Azure (https://azure.microsoft.com), and Amazon AWS Storage Solutions (https://aws.amazon.com/), each data record is represented as a separate instance of a commonly named *document*, regardless of its content and size. The documents contain information embedded in a searchable and filterable format. The commonly adopted format for these purposes is JSON (http://json.org), the standard data interchange format. It allows the storage of information using Artificial Intelligence (AI) technologies to learn the new facts from the data and find solutions necessary for improving energy efficiency. The most cited AI technologies are artificial neural networks (ANN), genetic algorithms (GA), and Bayesian (probabilistic) networks (PN).

Artificial neural networks (ANN) (often referred to as deep neural networks—DNN) use the collected and processed data as training sets for machine learning purposes. Furthermore, well-trained ANN represents a powerful tool for system optimization, decision-making support, and predictions (Lu et al., 2022). For instance, ANNs are commonly used for predicting the energy efficiency of buildings and business facilities (Tien et al., 2022). There are ANN subtypes known as convolutional neural networks (CNN). CNN specializes in advanced image / video content processing with high accuracy (so-called tensor flow technology). This way, CNN is used for discovering the traffic flow, heating maps, and occupancy patterns that are useful data for making optimizations and predictions on energy efficiency. Also, there is an example of CNN trained by datasets from different countries that are used in simulations for theft detection on electricity flow in the power grids (Arif et al., 2022).

Genetic algorithm (GA) represents another AI technology that fits multi-factor and multi-objective systems optimization. Smart cities represent such systems—a variety of energy sources and types of energy consumers (Liu et al., 2022). Their complexity is decomposed by using genetic concepts such as chromosomes (potential solutions for problems) and their parts—genes (one for each factor). The chromosomes are formed by collected and processed data. An evolutionary algorithm is used to combine genes of the chromosomes of one population by performing genetic operators like single and multiple crossovers (mutation is another genetic operator, infrequently used when there are no more advances with the existing chromosomes' genes). Further, the algorithm selects the chromosomes that best fit the solution. The GA repeats through several generations (iterations) and stops when there is no more progress in the solutions or when there is a finite number of iterations.

Case studies

Energy efficiency is one of the most important features of smart cities. Using the bottom-up approach it represents the aggregation of different efforts to improve the efficiency of individual objects (e.g., residential buildings, business facilities, public spaces, heating systems, power supply infrastructure, etc.) in the considered urban area. On the other hand, energy efficiency strongly corelates with other smart city features (e.g., waste and traffic management, air pollution monitoring and control, etc.). Therefore, improvements can be achieved only by means of comprehensive projects that involve all stakeholders, including local government, academic institutions, business partners, and non-governmental organizations. Moreover, some companies find their market niche in these, offering complete solutions for smart cities. Unfortunately, large-scale projects take a long time and a large expense to complete.

One of the most complete solutions is offered by *Fiware* (https://www.fiware.org/about-us/smart-cities/), a company with more than 300 smart city solutions made in 30 countries worldwide. Most of their implementations are in Spain, Sweden, India, Germany, Japan, France, and Italy. The solutions based on comprehensive approach that include management of buildings (energy and water consumption), waste management (control of location capacities and waste level), traffic management (traffic flow, street pollution, public traffic, e-vehicles control, parking control) and communications with citizens (citizen claims, location of issue, description of problems, and ASAP responses). Basically, the *Fiware* solution has a three-layer architecture. Sensors integrated with processing units are on the bottom: cameras with *Kurento* real-time media stream processing (https://kurento.openvidu.io/), IoT networks and platforms such as *OneM2M* (https://onem2m.org/), *FROST* (https://www.frost.com/), *EdgeX Foundry* (https://www.edgexfoundry.org/). The bottom level also includes connections with other information systems (e.g., Weather services, Air Quality trackers, social media, Smart parking, etc.). The data brokers form the middle layer, which provides contextual information for further processing in the top layer. These brokers group the information of the same category (e.g., energy consumption in specified areas) from different sources (e.g., from IoT platforms, and power grid sensors). The top-level (command and control) layer consists of different AI-based tools. Some examples are operation dashboards, advanced data maps, 3D visualization, business intelligence, and complex event processing.

On the other hand, there are a lot of good examples of low-cost projects for improving energy efficiency in cities. Local governments try to find partial solutions through small, specific projects, while top governmental institutions steer them toward the commonly defined goals. One of the interesting initiatives is from the neighborhood. Croatia, recognized as one of the most energy-intensive EU countries, has established energy management information system (EMIS) (Zekić-Sušac et al., 2021) that collects a variety of data (82 parameters) from 17000 public buildings to improve their energy efficiency. As a follow-up project, they build an intelligent system named MERIDA (Methodological Framework for Efficient Energy Management by Intelligent Data Analytics) designed for Big Data processing and predictive modeling of energy consumption of individual buildings, making smart buildings the backbone of future smart cities. The research recognized a deep neural network (DNN) and decision-tree models (*Random Forest, CTREE,* and *Rpart*) as the most appropriate solutions for predictive modeling. Data visualization and interpretation, as well as decision-making, are not included in the proposed solution.

Big data mining for the circular and energy efficiency city governance

For the purpose of this research, the energy efficiency big data management methodology was defined. It includes defining a set of indicators and developing the concept of a software model for collecting and processing data and for creating reports.

Defining a set of indicators

The Republic of Serbia has opted for sustainable development, but it faces a large number of obstacles along the way (Lior et al., 2018). Cities and local self-government units are often unable to independently finance the necessary changes and improvements, and the absence of strategic planning, national and local monitoring systems, as well as action plans that would improve the energy efficiency of cities and reduce pollution, is noticeable. Under such circumstances, it is necessary to develop a methodological approach mainly intended for local self-government units, enabling them to implement it independently and representing the starting point for all further urban plans.

In order to develop a certain methodological approach, i.e., to reduce the gap between the goals projected for the selected urban area (for the improvement of energy efficiency and environmental quality) and the results that would be achieved if no new activities were undertaken, it is necessary to define a set of indicators for:

- assessing energy efficiency resilience,
- assessing the gap analysis,
- implementation and
- monitoring and control.

The proposed list of indicators has been developed based on the authors' experience regarding energy management planning and a literature review of energy sustainability in urban planning.

a) Set of indicators for assessing energy efficiency resilience of the cities

A successful implementation of a situation analysis necessitates a complex and comprehensive process of collecting and analyzing specific indicators that best depict the energy status of the urban area (consumption and basic parameters of energy efficiency), such as:

- The amount of total energy consumed over a certain period of time in order to register seasonal oscillations in consumption (Barsocchi et al., 2018);
- The amount of total energy consumed in certain periods during the year, depending on the type of activity, since energy efficiency is one of the basic energy- and climate-related problems (Ignjatović et al., 2024);
- The amount of total energy consumed for heating (Waite et al., 2017), transportation (Sun et al., 2021), and other needs;
- The type (origin) of energy, as well as the amount of energy from individual sources (electricity, heat, coal, oil, gas);
- The ratio of local renewables production to local consumption of energy and electricity (Sarralde et al., 2011);
- Green mobility of the city, including electric and hybrid vehicle integration as well as the coverage of bike lanes in the urban area;
- Energy costs (by types and activities) for a period of one year;
- GHG emissions from energy use;
- Energy intensity by sector at the city level (Rad, 2010);
- Locally available finance schemes for energy efficiency and renewable energy (Amuakwa-Mensah & Näsström 2022);
- Public awareness campaigns relating to energy and circular economy issues (Neves & Leal, 2010);
- Public participation in energy-related policy-making (Francisco & Taylor, 2019).

In view of all the aforementioned, it is possible to gain insight into three basic indicators that must be defined in the process of sustainable energy management, namely: energy indicators (e.g., energy consumption, energy generation, losses in transmission and distribution), financial indicators (e.g., costs, investments), and energy transition improvement (e.g., energy intensity, carbon intensity). Given the availability of data, it is desirable to develop indicators that indicate a broader socio-economic aspect, such as health and well-being, as well as broader benefits, such as employment, added value (Desogus et al., 2024), or even social outcomes related to innovative solutions (Bisello & Vettorato, 2018).

In order to assess the development of a certain urban area, if the existing direction and rate of growth and progress continue without increasing energy efficiency, it is necessary to: a) analyze energy consumption in previous years, both by type and quantity; b) analyze the energy costs over the past few years; c) estimate the future growth rate of the urban area, depending exclusively on demographic trends; d) estimate future energy consumption by type; e) estimate future energy costs if the urban area continues to develop at a natural pace; f) evaluate the possibilities for providing the desired types and amounts of energy in the future; g) estimate future emissions based on energy consumption.

Based on the analysis of these data, an assessment can be made of future energy consumption, energy consumption costs, and energy efficiency (Angelidou et al., 2022). The assessment of the state in which the urban area is likely to find itself is associated with some level of uncertainty, which depends on the stability of general conditions, both in the country and at the global level. Moreover, the accuracy of this assessment can be considered acceptable for a period of up to five (maximum up to ten) years. However, this period may even be shorter in times of unstable conditions. Assessing the level the urban area should be achieving when it comes to the execution of sustainable energy management is based on predictions of the desired goals.

Taking into account the above, the urban area can assess its future situation following the introduction of measures aimed at improving energy efficiency based on the assessment of: a) total energy consumption in the future, which relies on the application of all measures to improve energy efficiency, i.e., constant measures of savings, optimization, and rationalization; b) future energy costs incurred as a result of reduced energy consumption, i.e., operations that are more energy efficient; c) investment made in order to achieve savings in energy consumption; d) future level of energy efficiency that may result from the implementation of sustainable energy management measures; e) financial and non-financial effects that may arise from the reduction of harmful emissions into the environment; f) the atmosphere and reactions of the international community and the citizens themselves to ecologically (ir)responsible behavior of the urban area (and the country as a whole); g) adherence to the regulations governing the implementation of measures to improve energy efficiency in urban areas, etc.

b) A set of indicators for assessing the gap analysis

As a rule, the future is unpredictable and the degree of risk always exists, with environmental and energy security often in contradiction (Radovanović et al., 2017). In the process of planning, it is necessary to understand the link between energy drivers (economic, environmental, technological, and social) and urban energy flows (Bettignies et al., 2019). Those drivers may help overcome planning and implementation barriers and transform any city's socio-ecological and socio-technical systems into a resilient city (Mendizabal, 2018). All of the above points to the need to develop special tools that will allow for more effective forecasting in this field. Determining the size of the gap between extrapolated and projected goals implies determining the difference that may appear in the future if certain changes are (not) introduced. When taking this action, it should be recognized that any process of change has its own causes and consequences. Therefore, the size of the expected gap at the city level will be greater if: a) a great number of companies are large consumers of energy, b) only energy from non-renewable sources is consumed, c) energy efficiency indicators are low, and d) there are changes in the plan of transition to a sustainable way of managing energy.

A properly conducted analysis of the gap between a state that is achieved without the introduction of changes and a state that can be achieved by applying sustainable management of energy and measures to improve energy efficiency is required to provide the following indicators: a) overall change in the amount of energy consumed; b) change in the amount of energy consumed, depending on the type of energy; c) the extent to which energy efficiency has changed, and d) the financial effects of the implemented changes.

When evaluating the economic profitability of introducing measures to improve energy efficiency, it is of particular importance to consider the financial implications and the timeline for anticipated effects, as this approach can mitigate financial instability. Accordingly, the urban area will be able to predict and implement the necessary allocation of resources in the long term, and anticipate the onset of positive financial impacts.

c) A set of implementation indicators

The implementation plan includes a range of measures and activities directly related to the need to reduce uncertainty arising from changes. This need is highly pronounced, particularly when introducing measures to improve energy efficiency. Given the aforementioned context, it is crucial to anticipate the following:

– The time frame required to move from traditional to sustainable way of energy management (Carreón & Worrell, 2018), which must be harmonized and integrated with other management plans, and practice shows that it takes a minimum of five years.

– Mechanisms for financing the implementation of the planned activities that lead to the full implementation of measures to improve energy efficiency might be pivotal in the transition process (Godfrey & Zhao, 2016). Therefore, it is necessary to boost local funds and the ability of cities to access capital for investment, support public and private investments through public–private partnerships, strengthen institutional capacity for investment planning, etc.
– An efficient implementation requires a new model of governance (Swilling & Hajer, 2017; Ehnert et al., 2018) and key personnel, both in terms of numbers and quality. It is necessary to plan training for different levels of employees, with the possibility of hiring personnel in charge of deployment, implementation, and monitoring of the sustainable energy management process, as well as the implementation of measures to improve energy efficiency.
– Public awareness and willingness of citizens and the business community to engage in the decarboniyzation might be crucial (Soma et al., 2018); (Rozhkov, 2024).

d) A set of monitoring and control indicators

Monitoring and control can conditionally be considered the last step in the implementation of measures to improve energy efficiency. The essence of the monitoring and control phase is to compare the achieved to the planned, identify possible deviations, and take corrective actions in order to adjust the process while striving for continual improvement. Therefore, this phase is only theoretically considered the last strategic step, whereas, essentially, it has a corrective role throughout the entire process of implementing measures to improve energy efficiency.

Goals are the object of monitoring and control, and one of the fundamental problems is defining the basis for comparison. The main problems with enforcing control in the process of implementing measures to improve energy efficiency are the frequency and determination of the objects of control.

The frequency of monitoring and control depends on a large number of factors, and it is important to consider their collective impact rather than analyzing them separately. In most cases, the control frequency is influenced by the following factors:

– Type of the subject of control, because more often, controls will be performed in companies that are large energy consumers (e.g., public transport and heating).
– The scope of measures to be implemented to improve energy efficiency because the measures can be implemented in different scopes – from partial and symbolic to comprehensive and complete.
– Experience in implementing measures to improve energy efficiency.
– The degree of changes coming from the environment (e.g., changes in the acceptance of certain legal and international obligations and contracts, changes in energy prices, etc.).
– The perception of the mentioned changes gained by the subjects of control and their experience in reacting to the changes.

Determining the objects of monitoring and control, i.e., the control points, must be aligned with previously set goals. Every goal set in the planning phase must be measurable in order to obtain data suitable for comparison in the control phase. Control points must be selected so as to provide data relevant to further measures in the energy management process in cities. The object of control can be any point where specific data is obtained. However, for the purpose of implementing measures to improve energy efficiency, the control points that are considered necessary are:

– Total energy consumption after a certain period is defined in the control plan (day, week, month), which provides information on the consumption trend.
– Determining the total energy consumption by sector, with a comparison of planned consumption and registration of all parameters that could impact the recorded level of consumption (capacity, type of product, technology, season, downtime).
– Determining the points of highest energy consumption in a certain period, with the aim of defining the point suitable for potentially greatest savings.

– Measuring the progress in transition (e.g., energy intensity, carbon intensity) and comparing that amount with the amount defined as a goal, with the purpose of determining whether the implemented measures lead to the goal at the desired pace. Defining the financial effects of implementing measures to improve energy efficiency. A comprehensive transition to sustainable energy management generally implies increased initial costs, so companies that typically consume large amounts of energy must prepare for the initial financial effects to be negative.

Even though energy (production, transmission/distribution, and consumption) and financial indicators are the most often used objects of control, if data are available, it is preferable to include the broader socio-economic impact (e.g., effect on health, well-being, etc.).Combining the obtained indicators allows one to understand the current state and behavior of the entire system and determine whether the city is moving toward efficient energy management or is failing to record such outcomes.

Defining a conceptual software model for analytical service for facilitating energy efficiency in city governance

The starting point and the input necessary for the functioning of the *Analytical Service* are primarily data describing energy efficiency. Optimally, data should be obtained from consumers because consumer habits and their changes are key factors in improving energy efficiency. Under the given circumstances in the Republic of Serbia, this is much more difficult (but possible), so the best solution in the initial stages of the *Analytical Center's* operations is the collection of data from external sources, as shown in Fig. 2.

As stated in Chapter 2, the proposal refers to a hybrid system solution that facilitates the ***collection of data from different Internet sources***: publicly available information from websites (e.g., LG, NGO, and business entities), information available through social networks (e.g., Twitter, Instagram, and Facebook), and available sensor data.

Collecting ***publicly available information from the Internet*** is preceded by the acquisition of websites, specifically, pages with content of interest. The acquisition is carried out using tools that facilitate customized website search (e.g., Google Search Engine, Bing Search Engine). These tools operate using a given set of keywords. Indispensable keywords include the name of the local community, names of economic entities operating on its territory, energy efficiency, energy consumption, energy saving, and the like. The system enables the administrator to update a set of keywords to permanently improve the search for information sources. The results of acquisition (i.e., Internet links) are forwarded to a Web scraping tool (e.g., Bright Data, Scrape, Nimble, Browse AI), which collects and extracts data of interest from given Internet sites, forwarding them in a formatted form (e.g., JSON, XML) to storage.

Social networks are another source of data. The system has two alternatives for collecting data from social networks: the Web Service specialized in monitoring social networks (e.g., Hootsuite) or locally installed software (e.g., Zoho CRM). In both cases, tracking is focused on a set of keywords, and communication, either with the Web Service or locally installed software, takes place through standard procedures (e.g., REST OpenAPI). Tracking results provided in a standard format (e.g., JSON) are placed by the system in the report storage.

The third source of data is the monitoring of data from ***available sensors***. The sources of this type of data are Web Services that can be accessed upon obtaining special permission from the owner. The entire infrastructure is built upon the Internet of Things (IoT) concept: sensors (e.g., electricity consumption) are connected to devices that facilitate remote monitoring, and data collection is performed by the owner's software that offers the data in the form of a Web Service accessed through standard procedures (as in the case of monitoring social networks). In addition, the system stores the data received from the sensors in the report storage.

The data obtained from final ***energy consumers*** is valuable, but this data is the most difficult to collect, especially when it comes to natural persons. On the other hand, citizens in the Republic of Serbia use energy inefficiently (especially for heating and transport), so it would be extremely important for urban planning and numerous other analyses to consider the specificities of consumption. In this regard, it should be borne in mind that data on energy consumption are diverse (prices of energy sources, seasonality, types of energy sources, method of consumption, purpose of consumption, etc.) and interdependent. The interdependence is not always clear, and a wide range of external factors influence its intensity and type. For this purpose, the *Analytical Service* uses a unique Web application that allows citizens to participate in surveys on energy consumption in their households.

The resulting data is stored in the ***Report Data Warehouse***, so named because each individual record contains data obtained by filtering and extracting from heterogeneous sources. Even reports from the same source can differ in size and structure, which happens in both cases: when extracting the contents from webpages and from the social networks' activity streams. The aforementioned characteristics suggest that records lack an implicit hierarchical structure and exhibit distinct formatting. Therefore, as a flexible and scalable solution, a NoSQL database management system would be used for data storage (e.g., MongoDB, Apache Air, and Apache Kafka). This system facilitates simultaneous, fast, and unified processing of differently structured data. In other words, it is not necessary to execute different queries for each data structure separately for the same goal.

The next module of the System is the ***Data Engineering Engine*** (e.g., Tableau, Apache Spark, Power BI, and Azure Data Factory). Its task is to facilitate batch and real-time data processing, which includes classification/clustering and the application of various methods of statistical processing and data analysis. The Report Data Warehouse and Data Engineering Engine enable efficient work with large amounts of data (BigData), as well as with time series data. Furthermore, the Data Engineering Engine allows for the application of machine learning in order to identify pattern changes in the data, draw conclusions about their mutual connections, and predict future trends as the concluding results of the System's operation.

The specified information (conclusions) is stored in the ***Knowledge base*** to make their multiple uses possible. In other words, the Data Engineering Engine uses the knowledge base contents for each subsequent cycle of data processing and reporting. This mechanism allows for permanent improvement in the *Analytical Service's* performance. Periodically, or when the need arises, the knowledge base contents are updated in order to achieve better results from the *Analytical Service.*

Although the listed examples of the Data Engineering Engine facilitate data visualization and advanced reports, external users do not have direct access to this component. For this reason, it is necessary to introduce an additional module that will facilitate the use of the System-***Reporting Web Services***. Only authorized persons have the right to access it from certain locations. This service is implemented as an intermediate layer that also allows for the resulting classification/clustering data, statistical processing, and data analysis to be integrated into the reports required by the above-mentioned users. This implies that the service contains components necessary for advanced reporting, dashboarding, data visualization, and *ad-hoc* queries. The mentioned technologies are mutually compatible because of standard data representations and connection interfaces (plug-ins and additional software libraries). However, due to the complex structure of data and in order to preserve system performance, it is recommended to use technologies paired with the Data Engineering Engine (e.g., Apache Spark with Spark SQL, Azure Data Factory with Azure Data Explorer, and Azure Analytics).

A special and complex problem faced by cities in the Republic of Serbia for several decades is ***city governance***. Apart from the introduction of analytical services (the proposal for one service is presented in this paper), it is necessary to continuously work on changing the traditional way of city governance in the Republic of Serbia in general, which has a rigidly hierarchical and inflexible structure burdened by bureaucracy and corruption. The above should be replaced by applying three basic models for urban area governance: a) multi-level governance (national, regional, local), which will facilitate active cooperation of all institutions at all three mentioned levels; b) cross-sectoral governance (with the inclusion of different sectors in which changes are possible in the direction of circularity), and c) quadruple helix governance, which is based on the cooperation of civil society organizations, the academic community, city administration, and business sector (Peter et al., 2023).

Considering the findings of this and associated research, as well as the significance of and need for resolving the issue of low energy efficiency in the

Republic of Serbia (as well as in other countries, primarily in Southeast Europe), more efforts must be made to enhance any activities that result in sustainable energy management. Monitoring energy consumption is undeniably a critical undertaking in this context; however, its technical implementation is exceedingly challenging, particularly given that energy monitoring in the Republic of Serbia is based on outdated methods. For many decades, there was no real-time monitoring of energy consumption, which was not an issue at a time when energy security and supply stability were unquestioned. Geopolitical shifts require significant enhancements to energy consumption monitoring. The proposed model is the first of its kind in the Republic of Serbia, but no practical testing has taken place yet due to the absence of regulatory, technical, or organizational prerequisites. Nevertheless, specific advancements have transpired as a result of the Republic of Serbia's implementation of regulations mandating that every local self-government formulate seven-year long-term development plans. These plans must contain a comprehensive evaluation of energy efficiency at the local level, among other components. The aforementioned mandates that local self-governments conduct energy consumption monitoring at specific measuring points and furnish annual data on consumption by the economy and population, in addition to information regarding the subtypes of energy sources. While a considerable number of local self-governments in the Republic of Serbia have yet to implement a monitoring system, it is mandatory for them to do so in order to facilitate future evaluations of their experiences. The model outlined in this paper explicitly necessitates collaboration among various stakeholders, including academia, businesses, local government, and the social community. The aforementioned facilitates methodological enhancements to the model and empowers local self-governments to develop the infrastructure and resources needed for applying big data mining to the collection of data necessary for energy efficiency. The Model of ***Analytical Service for facilitating energy efficiency in resilient urban area planning,*** which is proposed in this paper, represents an important aspect of the more comprehensive *Quadruple helix* model and is a contribution of the academic community. Considering the three basic approaches to urban area governance, the complexity and multidimensionality of the circularity approach, as well as the complexity and urgency of energy efficiency (a high degree of environmental risk in cities in the Republic of Serbia), it can be considered that the application of the *Quadruple helix governance* model is most acceptable and should be used in the future. On the other hand, intersectoral cooperation can be most effectively implemented solely at the local level. In that sense, it is necessary to further enhance the involvement of the public and private sectors, as well as the active participation of civil society, all in accordance with the specificities of each urban area. This is because the improvement in energy efficiency is closely related to the requirements, opportunities, and readiness for change of all participants at the local level.

Summary of results and further research directions

This paper employs conceptual research, indicating it does not rely on collecting and analyzing specific data and information. This is attributed to the lack of data, acknowledged as a significant problem faced by energy management in cities in the Republic of Serbia. For the reasons above, the research may be regarded as an innovative endeavor. Its findings and further research directions and activities are condensed in Table 1.

The research established the initial benchmarks for enhancing energy efficiency in the cities of the Republic of Serbia by implementing an analytical service, as demonstrated and elucidated in Table 1. A comprehensive list of essential indicators was established based on the requirements and available resources. Accordingly, methods for data collection, such as Row Data Warehouse, Data Engineering Engine, and Reporting, were presented to align with current capabilities.

Future research and activities should primarily concentrate on activating and linking institutions that need to be engaged in addressing the issue of energy efficiency in the Republic of Serbia. In the initial stage, this should mainly comprise collecting relevant data. The lack of data poses an insurmountable barrier to making informed decisions in this field going forward. City governance in the domain of enhancing energy efficiency necessitates the utilization of the

Table 1 Summary of research results and further research directions regarding the introduction of energy efficiency big data mining in city governance in the Republic of Serbia

No	Type of research result	Description	Further research directions
1	Analysis of literature and available regulations on energy efficiency big data mining in city governance in the Republic of Serbia	There is currently no organized and comprehensive data collection and analysis on energy efficiency in city governance in the Republic of Serbia	Developing strategies to influence policymakers in order to implement policies and action plans designed to facilitate the systematic collection of data
2	Analysis of case studies on energy efficiency big data mining in city governance in the Western Balkans region	Studies exist, but they are sporadic and designed as scientific projects, lacking data on practical application and results	Collaboration with the academic community, cities, and policymakers in the Western Balkans region and beyond, with the objective of sharing knowledge and experiences
3	A Conceptual Framework for an Energy Efficiency Analytics System	The proposal was developed and presented	Introduction of the proposed Energy Efficiency Analytics System in city governance as a pilot project in a selected number of cities with the aim of evaluating the system and making necessary adjustments after deployment, and redeployment until the optimal system is developed
4	A set of indicators for processing using the proposed Conceptual Framework for an Energy Efficiency Analytics System, which includes indicators for: - assessing energy efficiency resilience, - assessing the gap analysis, - implementation and - monitoring and control	The set of indicators is defined and explained	Evaluating the feasibility of the suggested set of indicators and making necessary adjustments

Table 1 (continued)

No	Type of research result	Description	Further research directions
5	Selection of data collection methods, including: - Web search - Customized Web Scraping - sensors monitoring (weather, traffic) - mobile network services for population density and mobility - social network monitoring - surveys	The methods are presented, and the justifications for their utilization are elucidated	Continuing to develop the approaches, evaluating their suitability for energy efficiency big data mining, and determining the optimal set of methods
6	Selection of methods for Row Data Warehouse, including: - API integration for real-time data access - data streaming for both structured and unstructured data		
7	Defining Data Engineering Engine – it represents the integration of frameworks for: - stream processing - data transformation - data classification and clustering - machine learning based on processed data		
8	Knowledge base—making conclusions by using trained AI tools and methods such as: - Expert systems, - Artificial neural networks, - Probability distribution systems, - Genetical algorithms, - Fuzzy logic systems,		
9	Reporting Web services – - Frontend RESTful Web services with different levels and controlled types of access over the Web apps and Web browsers		

most precise and dependable data, which should be collected and processed in an optimal manner.

The above represents a novel endeavor for the Republic of Serbia, but it is undeniably necessary, since enhancing energy efficiency is regarded as one of the urgent challenges that the country is confronted with. The country has been grappling with decade-long issues such as heavy reliance on imported energy sources, a significant proportion of energy expenses in the final product price, and the prevalent usage of coal leading to high (sometimes hazardous) levels of pollution. The issue of efficient energy use and the maximum reduction of energy imports is one of the priorities in the context of the new geopolitical constellation that is emerging on the global stage.

It is important to highlight that enhancing energy efficiency in cities should be meticulously planned and guided by regulatory guidelines. To effectively introduce analytical services, it is suggested to carry out pilot projects. The outcomes of these projects should be thoroughly analyzed, considering both the volume of data and the reliability of data processing.

The proposal above was tailored to the particularities of the Republic of Serbia, but it is applicable to other nations grappling with low energy efficiency metrics and a lack of structured data collecting and processing for this purpose. Only in this way can decision-makers be presented with inputs that will facilitate the formulation of new strategies, programs, and actions aimed at achieving long-term enhancements in energy efficiency and the mitigation of energy-related pollution in cities, countries, and beyond.

Conclusions

Modern urban planning should consider a large number of factors that will determine the quality of life and safety of inhabitants in the twenty-first century. In the first place, prerequisites and mechanisms must be provided to facilitate the reduction of the environmental burden created by inhabitants of urban areas and their activities. This will result in reducing the risk of inhabitants being exposed to the harmful consequences of pollution that they create. In this respect, the focus is primarily on the introduction of the principle of circularity, and especially on the improvement of energy efficiency.

The main goal of the paper is to assess the possibility of improving energy efficiency as one of the postulates of circularity in cities in the Republic of Serbia and to give recommendations for strategic planning, but only at the local level, while respecting local specificities. The Republic of Serbia faces a large number of challenges when it comes to urban planning in general. The crucial problems with the introduction of circularity in urban planning in the Republic of Serbia are energy efficiency and urban area governance. Each problem must be considered in accordance with its specificities, with an effort to develop approaches for their integration. Specifically, the introduction of a novel approach to urban area governance, strengthening of institutions, and utilization of modern approaches to planning are a basic prerequisite for planning and developing circular and resilient cities in the future. This is particularly the case regarding complex activities of priority for the Republic of Serbia—improving energy efficiency and reducing the high degree of environmental risk in its urban parts.

Finding solutions and introducing innovative approaches based on the principles of circularity is a long-term process that has not even begun. Therefore, this paper presents the first steps towards the development of a new methodology for facilitating circularity in urban planning, or at least certain principles thereof. It must be considered unrealistic to expect the Republic of Serbia to embrace all the principles of circularity in urban planning in the near future. However, it is certainly necessary to identify and solve the most pressing problems, which are, for cities in the Republic of Serbia, highly inefficient energy consumption and extreme, often hazardous, pollution in cities. The research is based on the specificities of the Republic of Serbia. It outlines the improvement in the process of facilitating circularity in urban planning when it comes to energy efficiency, with the proposal for introducing the ***Analytical Service model for facilitating energy efficiency in city governance***.

A flexible model was designed to allow for stable and permanent functioning, even in the absence of data from all the mentioned sources (e.g., no sensor system has been established, or no user survey has been carried out). On the other hand, the model can be expanded in case new types of data sources appear (e.g., economic entities commence releasing their data on energy consumption/savings). Moreover, the proposed architecture and technologies ensure the scalability of the model. This means that the implementation can be carried out at the level of one or more local government units, regardless of the size of the urban area. Furthermore, the model can be implemented as a cloud solution, thereby reducing the involvement of local government IT resources and streamlining coordination with other eGovernment services in data centers. Developing concrete mechanisms for tracking and monitoring, i.e., for the operationalization and financing of this approach, is a separate issue and is not the subject of this paper. Bearing in mind that cities in the Republic of Serbia apply a traditional approach to urban planning, which sporadically includes measures to improve sustainability, further research is open for many studies related to this issue.

It is imperative to note that the application of big data mining for local governance purposes is comparatively limited in the Republic of Serbia. Furthermore, the approach outlined in this paper represents an entirely novel concept, the acceptance of which necessitates the implementation of specific decisions at both the local and national levels. Consequently, any additional refinements to the proposed model (particularly in a technical sense) cannot be deemed practical until it has been evaluated under actual conditions.

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Declarations

Conflict of interest The authors hereby declare that they have no conflict of interest.

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