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TRANSITIONING TO GREEN CITIES: ANALYZING EUROPEAN URBAN DEVELOPMENT MODELS FOR SUSTAINABLE GROWTH

Alin-Cristian Maricuț
Bucharest University of Economic Studies, Bucharest, Romania
E-mail: alin.maricut@csie.ase.ro
ORCID 0000-0003-4599-1517

Diana Timiș
Bucharest University of Economic Studies, Bucharest, Romania
E-mail: diana.timis10@gmail.com
ORCID 0000-0002-5097-6007

Silvia Parusheva
University of Economics - Varna, Varna, Bulgaria
E-mail: parusheva@ue-varna.bg
ORCID 0000-0002-7050-3514

Slaveya Zhelyazkova
University of Economics - Varna, Varna, Bulgaria
E-mail: sjeliazkova@ue-varna.bg
ORCID 0000-0002-8133-9684

Giani Grădinaru
Bucharest University of Economic Studies, Bucharest, Romania
E-mail: giani.gradinaru@csie.ase.ro
ORCID 0000-0003-3336-1737

Zoltán Nagy
John von Neumann University, Kecskemét, Hungary
E-mail: nagy.zoltan@nje.hu
ORCID 0009-0000-0757-1381

ABSTRACT. The transition to green energy and sustainable urban planning, guided by EU policies and local community perceptions, has positioned the concept of the "green city" as a key topic in both academic and practical discourse. This study provides an in-depth analysis of the current understanding of green cities, while also identifying cities structurally prepared for this transition. The literature review highlights the significance of the green city concept, the strategic directions of the EU, and the perspectives of residents regarding what constitutes a green city. The research outlines two primary objectives: (1) identifying urban development models within a selected sample of cities, and (2) determining cities or groups of cities with the potential to implement the green city concept. Using data from the Organisation for Economic Co-operation and Development (OECD) and Open Street Map, we employed spatial indicators and calculated average distances to key points of interest, using R software for analysis. Principal Component Analysis and Random Forest predictive analysis algorithm were applied to classify urban development models, facilitating the identification of cities best equipped for green city implementation. The findings offer valuable insights into sustainable urban transitions, providing a data-driven approach to guide policymakers and city planners in fostering resilient and green urban environments. This research emphasizes the importance of integrating technological tools with human-centered urban planning for a sustainable future.

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Introduction

In the current European context where sustainable development has a very important role in the development of new projects, the way a city is planned represents a main pillar, from reconfiguration to redevelopment (Pinto & Akhavan, 2022). In the desire to face the challenges of the 21st century that are basically social and economic in nature, city dwellers have adopted a wide spectrum of characteristics that they consider necessary when relating to the city they consider suitable for living. The planning principles of a city should include two directions, on the one hand accessibility and mobility where we find in the analyzes indicators such as the average distance to a public transport station or the average distance to a charging station, on the other hand quality of life where we find indicators such as the number of green spaces or parks (Cohen, 2023; Zhao & Wan, 2020). Important in this regard remains the customers' intentions to use e-vehicles (Oláh et al., 2024).

In recent years, several economic models of cities have been developed around this hypothesis, including at the level of the European Union. They are differentiated primarily by the specific particularities of each region, but also by the culture, level of development, political decisions or already existing urban planning. Although all these economic models of cities share common principles such as the desire to have a variety of services in the appropriation of the residence, upon detailed analysis, it becomes evident that they differ significantly (Pozoukidou & Chatziyiannaki, 2021).

Following an analysis of the existing specialized literature, an association can be observed between the perception of the quality of life and the level of green areas in a city. Giannico et al. (2021) carried out a thorough study using a sample of 51 European cities in which they demonstrated that from the citizens' point of view urban management of the city and green spaces contribute to the general well-being of the inhabitants, reduce the effects of climate change and bring a significant contribution positive for health. This denotes the fact that the green city concept will be increasingly popular as a development model for European cities (Coisnon et al., 2024).

Moreover, according to the European Commission, over 70% of the total global greenhouse emissions are produced by cities (European Commission, 2023a). In this sense, clear commitments and an ambitious general plan have been created at the European level through which the European Union will achieve climate neutrality by 2050. There is a group of 100 cities that have been selected to test and bring solutions to the 3 main sectors green energy, waste management and urban development. The group belongs to the Horizon project and aims to involve the interested parties, the citizens and the internal governance in order to provide a model of good practices for other European cities (European Commission, 2022).

Analyzing both citizens' perceptions of urban green spaces and the European Commission's goal of achieving climate neutrality by 2050, it is evident that there is a clear shift towards green city development. As a result, the implementation of green city initiatives across cities in the European Union presents a compelling area for study (Chodkowska-Miszczuk & Lewandowska, 2024; Štreimikienė et al., 2022). Given the contemporary relevance and near-future applicability of this concept, our research aims to contribute meaningful insights to this growing field.

This paper examines the specific characteristics of prominent city concepts discussed in the existing literature and compares them with the green city concept. It also analyzes the European Union's strategic direction toward achieving climate neutrality by 2030. Additionally, the study investigates the perceptions of residents in European cities regarding the key attributes of a green city, offering a comprehensive perspective on how these urban initiatives align with policy objectives and public expectations.

In the second part of the paper, the analysis pursues two main objectives: (1) the identification of urban development models within the selected sample, and (2) – the identification of cities or groups of cities with potential for implementing the green city concept. To achieve these objectives, the first step involves preparing the database. Some data will be sourced from the OECD database, while additional information will be obtained from the collaborative open-source project, OpenStreetMap. To calculate average distances to points of interest, data from OpenStreetMap are processed using the R programming language. Principal component analysis is applied to identify urban development patterns within the selected sample, addressing the first objective. For the second objective, the random forest predictive algorithm classifies cities based on their EU membership status, country of origin, and development model. These analyses enable the characterization of each model using constructed indicators and identified specific features, facilitating conclusions about which cities are structurally prepared for the transition to the green city concept.

1. Literature review

In countries where urban development has been achieved rapidly, infrastructure and spatial planning have become a significant problem that architects try to rectify, and the solutions end up being extremely complicated (Abbott, 2002). From an urban governance perspective, analysis reveals that the shortage of affordable housing forces low-income households to reside in substandard living conditions. Rafieian and Kianfar (2023) developed in their work a theoretical framework to analyze existing policies concerning areas that do not fully adhere to official urban planning regulations yet are not deemed illegal. In this context, it is important to analyze both the evolution of development models and the direction of future trends.

Upon reviewing historical developments, urban modelling has undergone significant advancements over the past century, combining several disciplines such as economics, information science and sociology (Bashirpour Bonab et al., 2023). These models arose from the desire to create different development scenarios in order to make the best planning decisions for a city or region. According to Wang et al. (2024) urban models have evolved together with society, so although initially the main urban functions focused on transport and land use, nowadays there are complex interdisciplinary tools that act taking into account multiple factors such as social or environmental ones.

Initially urban modeling had two simple models such as Burgess's Concentric Areas Model (1925) and Hoyt's Sectoral Model (1939) that focused on income levels and distance from the city center. Along with the development of transport came the Model of Interaction between Land Use and Transport (LUTI) which brought a new approach to urban planning. In this context, emphasis was placed on the accessibility of transport and how it economically influences the respective areas (Abrams et al., 2012).

Currently, urban modeling has become extremely complex, given the consideration of all aspects of climate change. The integration of sustainable urban planning that prioritizes carbon footprint reduction and energy efficiency is desired, but there are numerous regulations that must be considered (Sutthichaimethee et al., 2024; Wang, Zhang & Zhong, 2019).

To successfully implement a city concept – whether it be a green city, smart city, or 15-minute city, it is essential to establish a legislative framework that addresses and rectifies previous planning errors (Munshifwa, 2023).

Considering the climate changes facing the entire planet and the measures of the European Commission it is important to mention the role of local government in achieving climate neutrality (European Commission, 2019). Although at first impression it seems that this green city concept is difficult to achieve or represents the distant future, the direction of the European Commission and the directives to the member states prove otherwise.

Currently, there are not many studies that address the topic of the green city concept, but according to the current measures communicated from Brussels, this type of urban development is the only solution towards a green and environmentally friendly economy (European Commission, 2023b). European projects such as the EU Mission for 100 smart cities and developed in accordance with current climate standards prove that governance structures are in a process of change (European Commission, 2023c). According to Kang et al. (2022) urbanization develops by focusing on the complexity of climate change and the involvement of stakeholders in the decision-making process. In addition, to the EU Mission for 100 cities project, there is the “Fit for 55” package which aims to reduce net greenhouse gas emissions by 55% by 2030 and achieve climate neutrality by 2050, providing a framework for action climate of cities (European Council, 2023). The package was developed following global studies that showed that more than 70% of greenhouse gas emissions come from urban areas. According to Shtjefni et al. (2024) and Savanevičienė et al. (2022) there must be a reform in governance, partnerships must be made, and local authorities must become managers of the transition.

Analyzing the definition of the green city concept, it can be seen that it includes all the important aspects regarding urban development. According to Shi, Wang, and Jing (2024) the main characteristics are: green spaces, renewable energy, ecological transport and low pollution. Cities of the future include creating green landscapes in concrete areas, reducing gas emissions or capturing and storing them as appropriate, lowering pollution indicators, building buildings to the highest standards that offer reduced resource consumption and significantly improving mobility (Bonab et al., 2023; Ngcobo, Akinradewo & Mokoena, 2024). In addition to the previously mentioned reasons, Delgado-Serrano et al. (2024) argue explaining that the implementation of the green city concept has a major impact on both physical and mental health. Currently, road noise pollutes sound and disrupts sleep, which leads to decreased cognitive performance. The green city concept has as its main functionality the increase of the quality of life of the inhabitants by creating a harmonious coexistence between nature and people.

In order to implement this city concept, a good coordination between European policies and national government is necessary. Solutions exist, but are often difficult to implement due to already existing urban development (Puppim de Oliveira et al., 2022). Architects have identified solutions, and in some European cities innovative projects are identified that are present as good practices in this direction. One of the solutions implemented by architects is the introduction of green areas in city centers to provide a soothing place to relax for all residents (Haaland & Konijnendijk van den Bosch, 2015). The English Garden in Munich is a very good example. Other identified solutions are the greening of facades and roofs by planting green spaces or simply planting trees and various plants.

Another important aspect of the green city concept is mobility which is structured in two directions: short distances for pedestrians and cyclists, where the urban plan of a city should identify shops for daily needs, public facilities, schools, recreation centers, but also medical offices in the vicinity of the place, and for long distances green transport (Wolch, Byrne & Newell, 2014).

Across Europe, many cities have already adopted or are actively working towards implementing the green city concept. For instance, Zurich places a strong emphasis on energy efficiency by adopting technologies that generate renewable energy, while also prioritizing sustainable mobility (Gabrielli et al., 2020). Copenhagen aims to become climate neutral in 2025 by focusing on the development of cycling infrastructure and the development of renewable energy (Maliszewska-Nienartowicz et al., 2024). Although Vienna does not limit the use of personal cars, it offers very well-developed public transport alternatives. Thus, residents use the bus or train network (Brenner et al., 2024). A final example identified would be the city of Stockholm, which in 2010 was declared the first green city in Europe because it has low carbon dioxide emissions and implemented technologies that provide renewable energy (Esmail et al., 2022).

In their paper on urban development, Spiliotopoulou and Roseland (2020) emphasized the importance of addressing consumption patterns and vulnerabilities, issues that gained prominence during the 2020 pandemic. It is very important that new policies fully integrate current economic progress and include an infrastructure adaptable to handle both long-term and short-term challenges.

According to the analysis developed by Guo and Zhang (2021) in the Texas Triangle, it can be seen that the regions differ a lot in terms of relief, but the main factors that influence urban development in a region are approximately the same. The study highlighted the fact that the main factors of expansion were economic growth, development of the transport network and population growth. As in other areas, in the last 25 years a more compact development model has been pursued, with an efficient use of land, but pro-sustainability initiatives bring major changes in the new urban plan.

Cervantes Puma, Salles, and Bragança (2024) noted in their study that despite growing interest in sustainable urban development and a strong commitment to green development models, progress toward the urban development goals of Agenda 2030 has remained limited. They highlighted that the process is challenging and requires innovative strategies to enhance energy efficiency and reduce carbon emissions.

2. Data and methods

To achieve the two research objectives, relevant variables, statistical units from various geographical areas, and appropriate statistical methods were selected. Based on the two working hypotheses, the sample was selected to capture both urban development models within the European Union and development models for cities that are not currently part of the European bloc (*Table 1*).

Table 1. Cities from EU and non-EU countries participating in the sample

Country	Cities	Region
Romania (EU)	Bucharest, Cluj-Napoca, Iasi, Constanta	Eastern Europe
Bulgaria (EU)	Varna, Sofia, Plovdiv, Burgas	Eastern Europe
Hungary (EU)	Budapest, Pecs, Debrecen, Miskolc	Eastern Europe
Spain (EU)	Madrid, Barcelona, Valencia, Bilbao	Western Europe
Netherlands (EU)	Amsterdam, Eindhoven, Rotterdam, Utrecht	Western Europe
Portugal (EU)	Porto, Lisbon, Coimbra, Braga	Western Europe
France (EU)	Paris, Lyon, Marseille, Bordeaux	Western Europe
Denmark (EU)	Arhaus, Aalborg, Copenhagen, Odense	Northern Europe
Finland (EU)	Helsinki, Tampere, Turku, Oulu	Northern Europe
Switzerland (non-EU)	Zurich, Bern, Geneve, Basel	Western Europe
Turkey (non-EU)	Istanbul, Ankara, Bursa, Antalya	Eastern Europe
Norway (non-EU)	Oslo, Stavanger, Trondheim, Bergen	Northern Europe

Source: *own compilation*

For a comprehensive analysis of the level of cities in EU member states, countries from all geographical regions were included. For example, the sample includes cities from Romania, Bulgaria, and Hungary, representing Eastern Europe; cities from Spain and Portugal represent Southwestern Europe; cities from Finland, Denmark, and the Netherlands are characteristic of Northern Europe; and cities from France typify Western European model.

Additionally, to ensure an equal distribution of cities in the sample for each country, four representative cities were selected from each country. Finally, the resulting sample comprises 48 cities from 12 countries, of which 9 are EU member states and 3 are non-EU member states.

Table 2. Units and data sources for the variables characterizing cities

Variable	Unit of measure	Data Source
GDP per capita	Dollars per capita	OECD
Employment rate	%	OECD
Population density	Citizens per sqm	OECD
Urbanised area per capita	Sqm per capita	OECD
Green area per capita	Sqm per capita	OECD
Mean population exposed to PM 2.5	%	OECD
Average distance to bus stations	Meters	Open Street Map
Average distance to charging station	Meters	Open Street Map
The Share of ten floors building	%	Open Street Map

Source: *own compilation*

Table 2 represents units and data sources for the variables characterizing cities. The variables sourced from the OECD database were directly extracted from their interactive online platform. In contrast, for the variables sourced from Open Street Map, these were calculated by the authors in R as follows. Average distance variables were computed as the mean distances from residential buildings (houses, apartment blocks, other types of residential buildings) to points of interest, in this case, bus stations, charging stations, and educational units (kindergartens, schools, high schools). To determine these average distances, the first step was selecting the geospatial polygon for each city. Subsequently, based on the polygon coordinates, geospatial coordinates for the residential buildings and points of interest (charging stations, bus stops, and education units) were extracted. The next step involved extracting the geospatial coordinates for the entire road network. Finally, using the R software package dodgr, individual distances from residential buildings to points of interest were calculated. The last step was calculating the average of all individual values. However, there were instances where individual distance values were infinite, indicating that there were no roads connecting point A to point B. In such cases, aerial distances in the spatial profile were calculated. Density-type variables were computed by extracting all polygons representing parks or green spaces (greenfield, grass). Individual areas were then calculated, summed, and the total area was reported relative to the city's total area. The Share of ten floors building variable was calculated as the ratio of the number of 10 floors buildings to the number of buildings with 10 and 4 stories, thus characterizing the type of residential development in urban environments.

To achieve the two objectives, two complex statistical methods were used. For identifying urban development models within the selected sample, principal component analysis was used. This method offers several advantages, such as reducing the large dataset into p principal components, where variables within each principal component are correlated with each other, while the p principal components themselves are uncorrelated (Peng et al., 2023). Another advantage is the ease of characterizing statistical units on the p resulting principal components through graphical representations. To select the p principal components, it is necessary for them to collectively explain at least approximately 70% of the variation in the entire dataset. Additionally, the eigenvalues associated with the principal components are important; they should be at least equal to 1. An eigenvalue below 1 indicates that a principal component explains less variation in the dataset than an individual variable (Inostroza & Tábbita, 2016).

On the other hand, to address the two objectives, the random forest classification algorithm was used. This classification algorithm is highly effective, minimizing classification error because it relies on bootstrap sampling, using independent samples for classification (Zhang et al., 2024). Unlike classic random tree algorithms, the number of predictors is equal to the square root of the total number of explanatory variables (predictors) (Kim et al., 2024). This method is used to classify cities as either EU or non-EU, capital or non-capital, and to categorize them based on their respective countries or regions.

3. Results and discussion

3.1. Extracting principal components of urban development variables

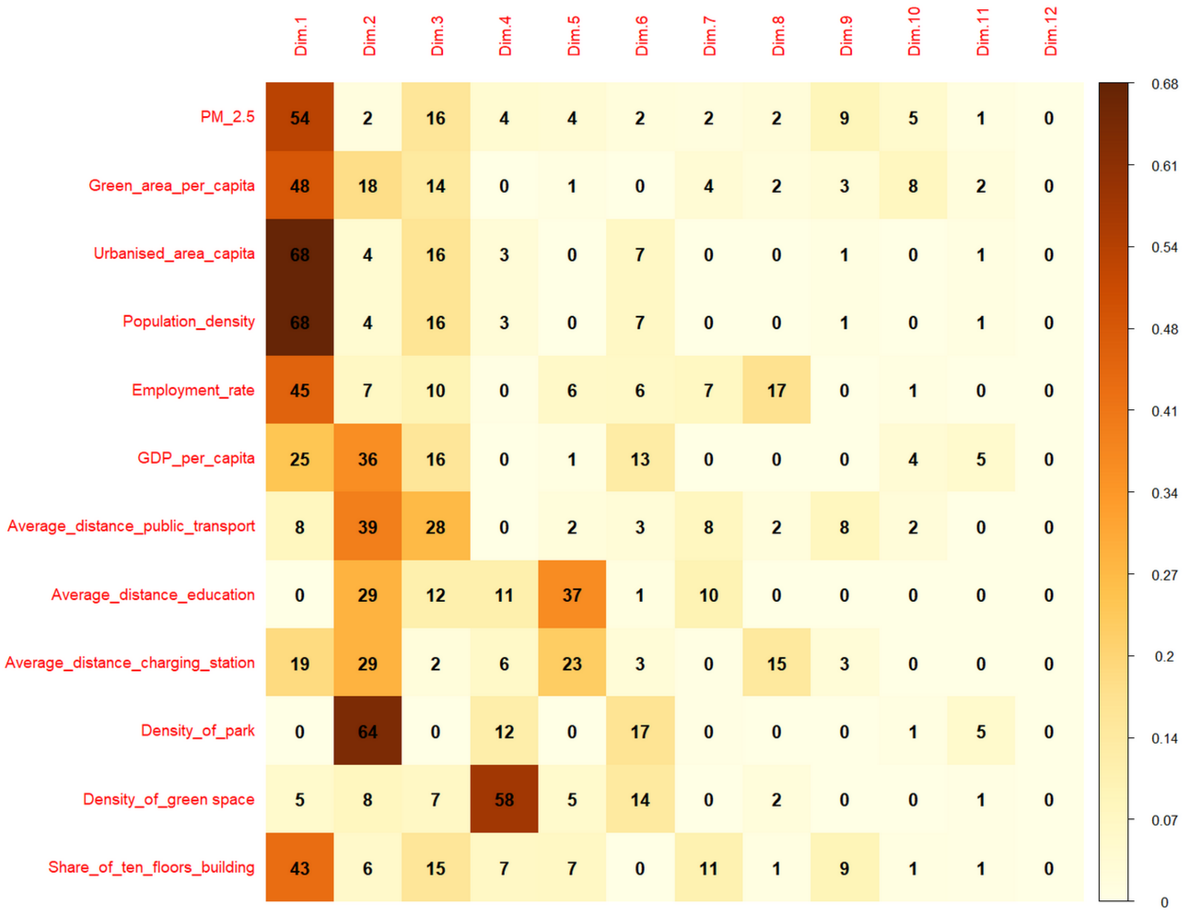
Principal component analysis is used to identify how the variables are associated, but also to describe the pattern of urban development of the cities included in the sample. The results form from principal component analysis are presented in *Table 3*.

Table 3. Results from principal component analysis

Principal Component	Eigen value	Cumulative variance explained
1	3.83	31.98
2	2.46	52.47
3	1.51	65.06
4	1.04	73.75
5	0.86	80.92

Source: *own compilation*

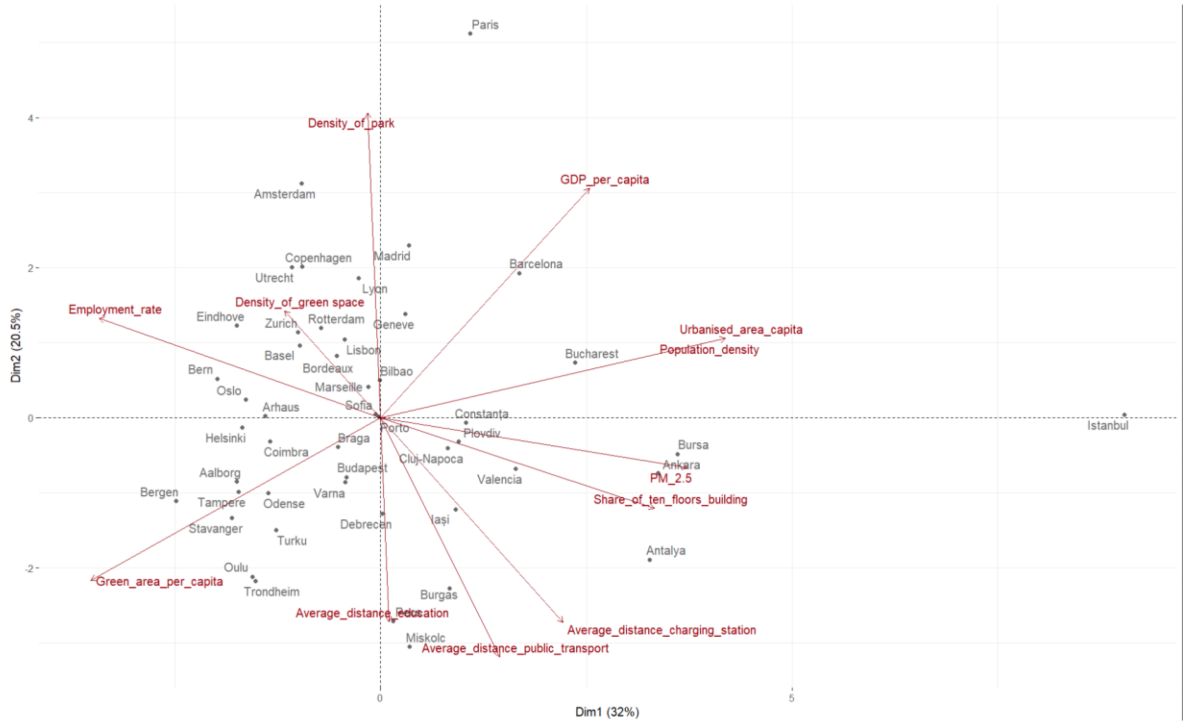
The first four components explain a greater proportion of the variation than the individual variables would explain, with them explaining about 74% of the variation in the entire data set. However, the eigen value associated with component 4 is equal to 1.04, very close to value 1. Thus, it can be considered that the fourth main component explains a little more than the variation of an individual variable.



Graph 1. Principal components of urban development variables
Source: *own compilation*

Analyzing the quality of the representation of the variables on each principal component, it can be seen that none of the variables is best represented on the third principal component. Thus, given that 4 principal components have recorded eigenvalues above 1, but none of the variables is best represented by principal component 3, only three principal components will be selected.

Thus, the first main component is made up of variables, such as: PM 2.5, Employment rate, Urbanized area per capita, Green area per capita, Population density and Share of ten floors building. The second component consists of variables such as: Density of park, Average distance charging station, Average distance education, Average distance public transport and GDP per capita. Finally, component 3 is made up of a single variable, Density of green space.

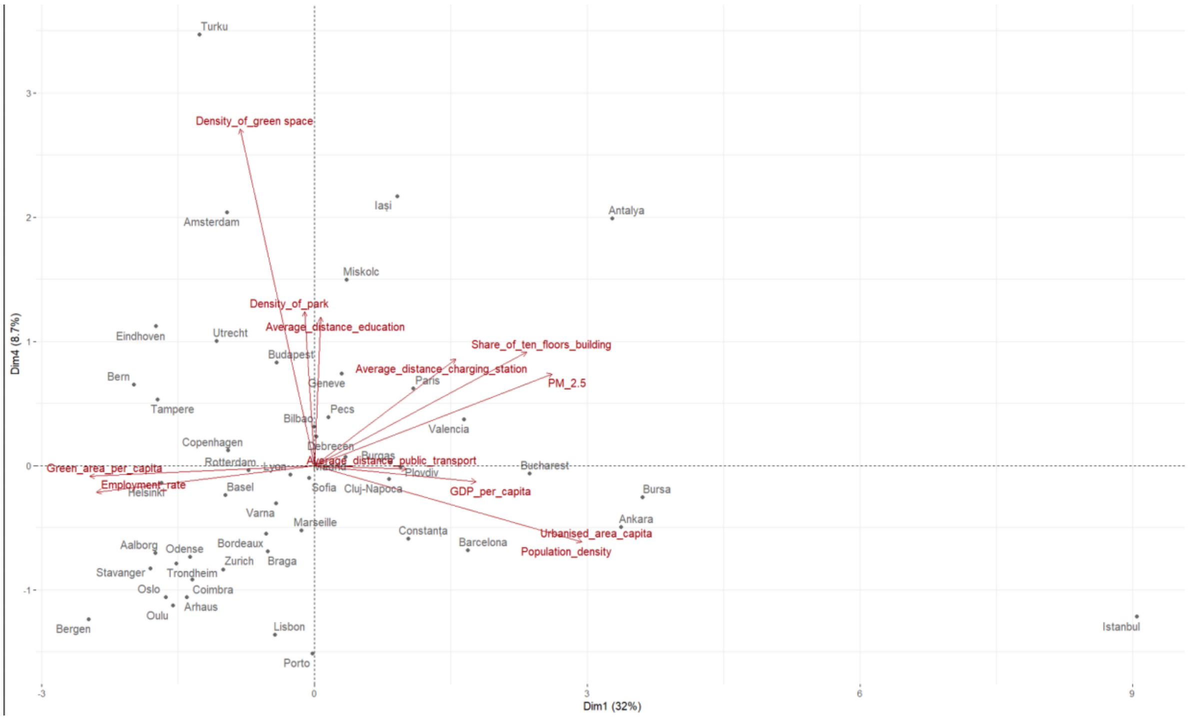


Graph 2. Patterns of urban development by region
Source: *own compilation*

Analyzing the quality of the representation of the variables on each principal component, it can be seen that none of the variables is best represented on the third principal component. Thus, given that 4 principal components have recorded eigenvalues above 1, but none of the variables is best represented by principal component 3, only three principal components will be selected.

In addition, several patterns of urban development can be identified. For example, cities in northern Europe and Switzerland are characterized by high inclusion on the labor market, but also a high density of green spaces. On the other hand, the cities of Eastern Europe, especially Miskolc, Burgas and Iași, are characterized by relatively low urban mobility, a high level of pollution and a significant share of green spaces, confirming the idea of urban development in the absence of planning (Abbot, 2002). Bucharest and Barcelona are two other cities prominently featured in the first main component. Both cities are characterized by high GDP per capita, significant population density, and Urbanized area per capita, while exhibiting low values in terms of Green area per capita. Based on this characterization, local public administrations should focus on developing and implementing a plan to facilitate the transition toward the green city concept (Shtjefni et al., 2024). Furthermore, to address past planning errors, the adoption of concepts like the green city, smart city, or 15-minute city can be pursued (Munshifwa, 2023).

Thus, it can be said that cities in Switzerland are marked by short distances from residential areas to points of interest, supporting the idea put forward by Gabrieli et al. (2020). On the other hand, cities in the Netherlands are characterized by green spaces, while cities in Turkey are characterized by a high population density and a high pollution level.



Graph 3. Representation of cities on green space density component
Source: *own compilation*

The third component, which represents the density of green spaces, shows that the city of Turku (Finland) is strongly represented, with a notably high density of green spaces. Also, Dutch cities (Amsterdam, Utrecht, Eindhoven) are also characterized by a high density of green spaces. On the other hand, the cities in Norway (Oslo, Bergen, Stavanger and Trondheim) are cities that present low densities of green spaces, mainly as a result of landform existing in these cities. Similar to these cities, Lisbon, Porto, Coimbra and Athens are other cities that are characterized by a low density of green spaces. A solution for increasing the density of green spaces in these cities could be the development of green areas like the English Garden in Munich, as supported by Haaland and Konijnendijk van den Bosch (2015).

To achieve the primary objective of identifying urban development patterns among the cities in the sample, four Random Forest classification models were developed. In the first model, the dependent variable represents the country of origin of the cities. The second model classifies cities based on their membership in the European Union, distinguishing between cities in EU member states and those in non-member states. The third model uses a dichotomous dependent variable to differentiate between capital cities and non-capital cities. Finally, the fourth model categorizes cities according to their geographical region within Europe (Northern, Western, or Eastern).

3.2. Identifying patterns at the country level

The random forest classification model was estimated using the country of each city as the dependent variable, and the rest of the variables played the role of exogenous variables.

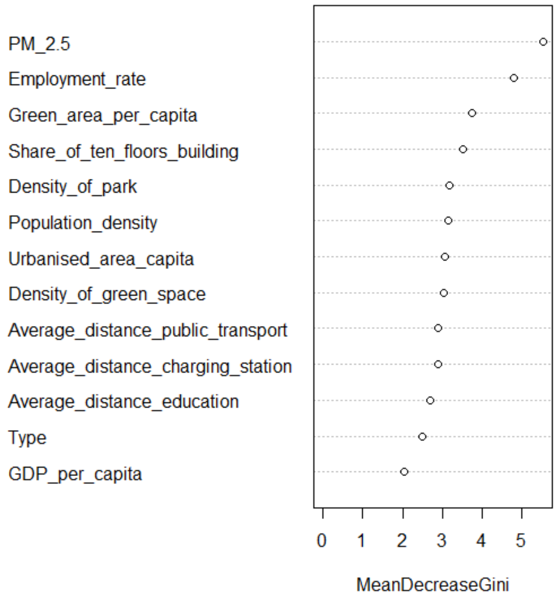
Table 4. Classification error by country in random forest model

Country	Classification error %
Bulgaria	50
Denmark	50
Finland	50
France	25
Hungary	25
Netherlands	0
Norway	0
Portugal	50
Romania	75
Spain	75
Switzerland	25
Turkey	0

Source: *own compilation*

The model provides perfect accuracy for the classification of cities in the Netherlands, Norway and Turkey. In other words, these three countries show a pattern of urban development. If the cities of the Netherlands and Norway are characterized by a low population density, relatively low distances on the urban mobility zone, increased inclusion on the labor market and a horizontal residential development, the cities of Turkey present a high population density, a high level of pollution and a vertical residential development. On the other hand, at the level of Spain, Romania, Portugal, Finland, Bulgaria and Denmark, no structural model of urban development was identified, the classification error being at least 50%.

For Switzerland, France, and Hungary, it can be said that there is a consistent structural model of urban development, with only one statistical unit misclassified. In the case of France and Hungary, the capitals Paris and Budapest are the only cities incorrectly classified. Thus, it can be stated that at the national level there is the premise of structural urban development, but at the level of the capital the situation changes, the urban development model being influenced by other factors as well. In the case of Switzerland, Geneva is the only city wrongly classified, a fact that can be translated by a cosmopolitan character of this city. The significant differences regarding classification errors at the country level complement the idea stated by Puppim de Oliveira et al. (2022), that solutions for uniform urban development exist, but are difficult to implement within the existing urban development.



Graph 4. Key variables impacting country-level classification
Source: *own compilation*

In this classification, the variables PM_2.5, inclusion on the labor market (Employment rate), Green area per capita and the residential development model (Share_of_ten_floors_building) were of major importance. At the opposite pole, GDP per capita, Type (whether or not the reference country is a member of the European Union), but also the variables associated with urban mobility, generated a minor impact on classification.

3.3. Identifying urban development patterns according to the cities' membership in the European union

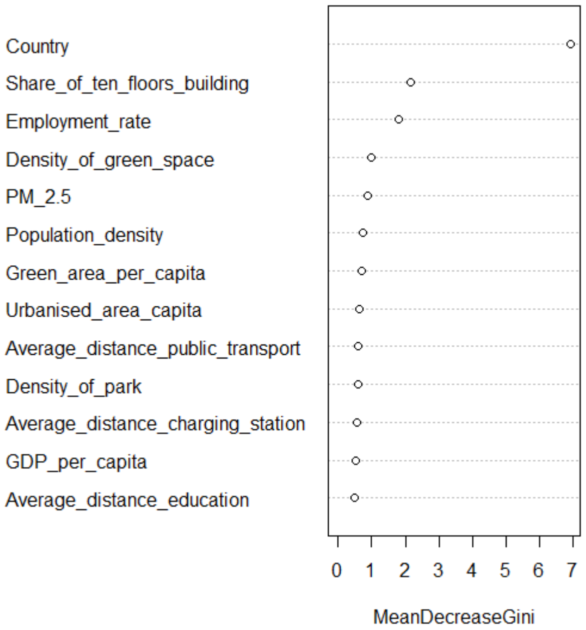
In order to identify if there are structural differences between the cities that belong to member states of the European Union and those that do not, a random forest model was estimated, with the endogenous variable type (EU and non-EU), and the rest of the variables played the role of exogenous variables.

Table 5. Classification errors of random forest model for EU and non-EU cities

Type	EU	Non-EU	Classification error %
EU	36	0	0
Non-EU	0	12	0

Source: *own compilation*

As can be seen, the model perfectly classifies the cities according to their membership of the European Union. Thus, the 36 cities from the member states of the European Union are correctly classified, generating a classification error of 0%. Similarly, the other 12 cities in Switzerland, Turkey or Norway, non-EU countries, are 100% correctly classified, yielding 0% classification error. Therefore, it can be stated that at the level of the European Union there is a different pattern of urban development compared to the cities in the states that have not joined the European Union.



Graph 5. Key variables impacting EU vs non-EU city classification
Source: *own compilation*

As expected, the qualitative variable Country has the greatest importance in the classification. Therefore, the biggest impact on this classification is determined by the typology of the country from which the cities originate. However, in addition to this variable, important predictors in the classification are Share of ten floors building and inclusion on the labor market (Employment_rate).

As a general conclusion, it can be stated that there are structural differences regarding urban development between the member states of the European Union and the states that are not part of the Union. Thus, the hypothesis of a comprehensive development at the level of all the member states of the European Union can be confirmed.

3.4. Identifying urban development patterns according to the cities' typology (capital/non-capital)

In order to identify if there are structural differences between the cities which are capital of a country and the others which are not, a random forest model was estimated, with the endogenous variable type (EU and non-EU), and the rest of the variables played the role of exogenous variables.

Table 6. Classification errors of random forest model for capital and Non-capital cities

Type	Capital	Non-capital	Classification error %
Capital	0	11	100
Non-capital	4	33	10.8

Source: *own compilation*

The results in *Table 6* indicate a 100% error concerning the cities that are capitals in the sample, as they were incorrectly classified as Non-Capital cities. Although the classification error for the Non-Capital alternative is relatively low, at 10.8%, the classification results suggest that it cannot be asserted that there is a specific urban development model at the level of capital cities. Therefore, this qualitative variable does not significantly influence the urban development model. As a result, given the high classification error associated with the model, the importance of the predictors in this classification will not be analyzed. This result confirms the idea stated by the European Commission (2019), which mentions the fundamental role of local public administration in urban development.

3.5. Identifying urban development patterns according to the cities' regions

The random forest classification model was estimated using the region of each city as the dependent variable, and the rest of the variables played the role of exogenous variables, except the qualitative variable Capital/Non-Capital. The cities were allocated to regions as it is described in *Table 1*.

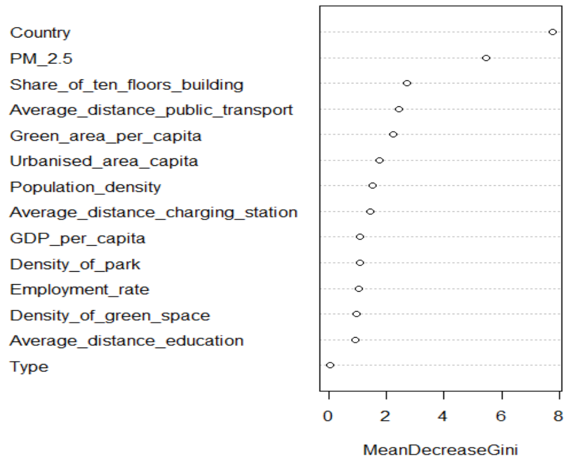
Table 7. Classification errors of random forest model for cities regions

Type	Northern Europe	Western Europe	Eastern Europe	Classification error %
Northern Europe	10	2	0	16
Western Europe	1	19	0	5
Eastern Europe	0	0	16	0

Source: *own compilation*

The classification of cities based on the European region they originate from reveals the existence of an Eastern European urban development model, with a classification error of 0% for these cities. Moreover, other cities belonging to countries in Western and Northern Europe are not incorrectly classified as part of Eastern Europe (*Table 7*). Thus, it can be stated that, within the sample, the Eastern European urban development model is identified. On the other hand, classification errors are relatively low for cities from Northern Europe (16%) and Western Europe (5%), with only four cities being misclassified by the model. Interestingly, the Western European city classified as belonging to Northern Europe is Coimbra, Portugal, while the Northern European cities classified as originating from Western Europe are Oslo (Norway) and Copenhagen (Denmark). These two capitals from Northern Europe significantly resemble the urban development model promoted in Western Europe. Therefore, it can be inferred that there are many similarities between the urban development models of Western and Northern Europe, both focused on pollution reduction and transitioning toward the green city concept, yet there are also structural differences compared to cities in Eastern Europe. Building on this result, cities in Eastern Europe can apply the best practices already implemented in cities in Western and Northern Europe. For example, they can implement measures to reduce carbon emissions by adopting technologies that produce renewable energy, similar to the city of Stockholm (Esmail et al., 2022).

Given the classification quality, it is important to analyze the significance of the predictors in the classification process.



Graph 6. Key variables impacting region-level classification
Source: *own compilation*

Similar to previous cases, the primary predictors are the city's country of origin, pollution levels, and the type of residential development, whether vertical or horizontal. On the other hand, factors that contribute less to classification include the country's EU membership status and the Average Distance to Education (*Graph 6*).

Conclusion

There are significant structural differences between cities in the European Union member states and those in non-EU countries, specifically in nations such as Turkey, Switzerland, and Norway. Even so, there are also differences in urban development within cities in the three non-EU countries, as well as among cities in EU member states. For example, cities in Turkey (Istanbul, Ankara, Antalya, and Bursa) are characterized by high population density, elevated levels of pollution, challenges regarding labor market inclusion, and a vertical pattern of residential development. Additionally, these cities face issues related to urban mobility, being structurally unprepared for the replacement of conventional vehicles with electric ones. On the other hand, cities in Switzerland (Zurich, Basel, Geneva, Bern) are well-developed in terms of urban mobility, with short distances between residential buildings and points of interest. Moreover, these cities are highly economically developed, generating a very high GDP per capita. Regarding residential development, Swiss cities are characterized by horizontal expansion, with a relatively small number of tall buildings.

Cities in Norway (Oslo, Stavanger, Bergen, Trondheim) are marked by significant distances between residential buildings and bus stations. This is mainly due to Norway's territorial characteristics, as well as the use of unconventional modes of transportation. Similar to the cities in Norway, those in Finland (Oulu, Helsinki, Tampere, Turku) exhibit the same pattern in terms of access to above-ground public transportation. However, in other respects, Norwegian cities resemble those in Switzerland, being characterized by low pollution levels, high economic performance, and horizontal residential development. Additionally, these cities are prepared for a greater adoption of electric vehicles, like cities in the Netherlands (Amsterdam, Utrecht, Eindhoven, Rotterdam).

Within the European Union, several economic development models can be identified. The model in Eastern Europe, characterized by cities in Romania, Bulgaria, and Hungary, is distinguished by vertical residential development, high population density, and limited infrastructure for transitioning to green vehicles. On the other hand, cities in Western and Northern Europe propose a model of horizontal residential development, low pollution levels, low population density, and high performance in urban mobility. These cities are also well-prepared for the transition to electric vehicles.

Even though there is no classification error when categorizing cities within the EU or non-EU zones, with the country of origin being the most important predictor, three urban development models were identified when classifying cities by country of origin: the Dutch model, the Turkish model, and the Norwegian model. Thus, it can be stated that the Turkish model is characterized by high pollution levels, driven by population density, economic development patterns, and a lack of public transport efficiency. Moreover, cities in Turkey are not structurally prepared for the transition to the green city concept. The Dutch model is characterized by efficient urban mobility, low pollution levels, and an effective economic development model. In addition, from the perspective of residential development, cities in the Netherlands are horizontally developed, with low-rise buildings predominating. The model promoted by Norwegian cities is like the Dutch model, with the only difference being the longer distances in urban mobility in Norwegian cities. However, cities in both Norway and the Netherlands are structurally prepared for the transition to electric vehicles.

The limitations of the research pertain to the comparability of data over time. For each variable, the value associated with the most recent year was selected at the level of each statistical unit. Another limitation of the research is the calculation of average distances from residential buildings to public transport stations. This type of distance was calculated only for above-ground public transport stations, underestimating the development of public transport in Northern European cities, particularly in Finland and Norway, which have predominantly developed underground transport as well as urban water transport.

To increase the relevance of the research results for informing local public administration decisions, future research directions include expanding the number of statistical units in the sample, as well as increasing the number of cities from non-EU countries. Another direction for future research is to group cities according to their size based on the number of inhabitants and then apply the random forest classification in order to determine whether the size of the city predetermines a specific pattern of urban development. The research can also be developed in the future with the application of cluster analysis to group the cities based on the variables included in the study.

References

Abrams, J. B., Gosnell, H., Gill, N. J., & Klepeis, P. J. (2012). Re-creating the rural, reconstructing nature: An international literature review of the environmental implications of amenity migration. *Conservation and Society*, *10*(3), 270-284. https://doi.org/10.4103/0972-4923.101837.

Bashirpour Bonab, A., Fedele, M., Formisano, V., & Rudko, I. (2023). In complexity we trust: A systematic literature review of urban quantum technologies. *Technological Forecasting and Social Change*, *194*, 122642. https://doi.org/10.1016/j.techfore.2023.122642.

Abbott, J. (2002). An analysis of informal settlement upgrading and critique of existing methodological approaches. *Habitat International*, *26*(3), 303–315. https://doi.org/10.1016/S0197-3975(01)00049-2.

Bonab, A. B., Bellini, F., & Rudko, I. (2023). Theoretical and analytical assessment of smart green cities, *Journal of Cleaner Production*, *410*, 137315. https://doi.org/10.1016/j.jclepro.2023.137315.

Brenner, A.-K., Haas, W., Rudloff, C., Lorenz, F., Wieser, G., Haberl, H., Wiedenhofer, D., & Pichler, M. (2024). How experiments with superblocks in Vienna shape climate and health outcomes and interact with the urban planning regime. *Journal of Transport Geography, 116,* 103862. https://doi.org/10.1016/j.jtrangeo.2024.103862.

Cervantes Puma, G. C., Salles, A., & Bragança, L. (2024). Nexus between Urban Circular Economies and Sustainable Development Goals: A Systematic Literature Review. *Sustainability, 16*(6), 2500. https://doi.org/10.3390/su16062500.

Chodkowska-Miszczuk, J. M., & Lewandowska, A. (2024). Cities facing the European green deal: Urban policy and locals' perspective in the post-socialist area. *Environmental Science & Policy, 159,* 103823. https://doi.org/10.1016/j.envsci.2024.103823.

Cohen, E. (2023). The increase in the number of vehicles and the shortage of parking in Israel's urban areas - economic and political factors. *Economics and Sociology, 16*(2), 37-55. doi: 10.14254/2071-789X.2023/16-2/3

Coisnon, T., Musson, A., Pene, S. D., & Rousselière, D. (2024). Disentangling public urban green space satisfaction: Exploring individual and contextual factors across European cities. *Cities, 152,* 105154. https://doi.org/10.1016/j.cities.2024.105154.

Delgado-Serrano, M. M., Melichová, K., Mac Fadden, I., & Cruz-Piedrahita, C. (2024). Perception of green spaces' role in enhancing mental health and mental well-being in small and medium-sized cities. *Land Use Policy, 139,* 107087. https://doi.org/10.1016/j.landusepol.2024.107087.

Esmail, B. A., Cortinovis, C., Suleiman, L., Albert, C., Geneletti, D., & Mörtberg, U. (2022). Greening cities through urban planning: A literature review on the uptake of concepts and methods in Stockholm. *Urban Forestry & Urban Greening, 72,* 127584. https://doi.org/10.1016/j.ufug.2022.127584.

European Commission. (2019). *National energy and climate plans: EU countries' 10-year national energy and climate plans for 2021-2030. Clean Energy for All Europeans Package*. https://commission.europa.eu/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en [Accessed September 10, 2024].

European Commission. (2022). *The Commission designates the 100 cities that will participate in the EU mission for climate-neutral and smart cities by 2030*. https://ec.europa.eu/commission/presscorner/detail/en/IP_22_2591 [Accessed September 5, 2024].

European Commission. (2023a*). Report on the implementation of Directives 2004/107/EC and 2008/50/EC on ambient air quality*. Brussels: European Commission. Retrieved September 12, 2024, from https://www.europarl.europa.eu/doceo/document/A-9-2021-0037_EN.pdf.

European Commission. (2023b). *The European climate law. European Green Deal*. https://climate.ec.europa.eu/eu-action/european-green-deal/european-climate-law_en [Accessed September 10, 2024].

European Commission. (2023c). *EU mission: Climate-neutral and smart cities.* Horizon Europe. https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/climate-neutral-and-smart-cities_en [Accessed September 10, 2024].

European Council. (2023). *Fit for 55. The EU Plan for a Green Transition*. https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/ [Accessed September 10, 2024].

Gabrielli, P., Acquilino, A., Siri, S., Bracco, S., Sansavini, G., & Mazzotti, M. (2020). Optimization of low-carbon multi-energy systems with seasonal geothermal energy storage: The Anergy Grid of ETH Zurich. *Energy Conversion and Management: X*, *8*, 100052. https://doi.org/10.1016/j.ecmx.2020.100052.

Giannico, V., Spano, G., Elia, M., D'Este, M., Sanesi, G., & Lafortezza, R. (2021). Green spaces, quality of life, and citizen perception in European cities. *Environmental Research*, *196*, 110922. https://doi.org/10.1016/j.envres.2021.110922.

Guo, J., & Zhang, M. (2021). Exploring the patterns and drivers of urban expansion in the Texas Triangle Megaregion. *Land*, *10*(11), 1244. https://doi.org/10.3390/land10111244.

Haaland, C., & Konijnendijk van den Bosch, C. (2015). Challenges and strategies for urban green-space planning in cities undergoing densification: A review. *Urban Forestry & Urban Greening*, *14*(4), 760–771. https://doi.org/10.1016/j.ufug.2015.07.009.

Inostroza, L., & Tábbita, J. H. (2016). Informal urban development in the Greater Buenos Aires Area: A quantitative-spatial assessment based on households' physical features using GIS and principal component analysis. *Procedia Engineering*, *161*, 2138–2146. https://doi.org/10.1016/j.proeng.2016.08.806.

Kang, Y., Feng, H., Zhai, P., & Guo, K. (2022). A bibliometric analysis on urban climate governance. *Procedia Computer Science*, *214*, 973–982. https://doi.org/10.1016/j.procs.2022.11.267.

Kim, J.-H., Kim, D., Jun, H.-J., & Heo, J.-P. (2024). The detection of residential developments in urban areas: Exploring the potentials of deep-learning algorithms. *Computers, Environment and Urban Systems*, *107*, 102053. https://doi.org/10.1016/j.compenvurbsys.2023.102053.

Maliszewska-Nienartowicz, J., Michalak, B., Modrzyńska, J., Piechowiak, J., & Szpak, A. (2024). The energy transition in the cities of Copenhagen, Helsinki, and Stockholm: Similar or different pathways towards the EU's 2030 targets? *Urban Climate*, *55*, 101887. https://doi.org/10.1016/j.uclim.2024.101887.

Munshifwa, E. K. (2023). Institutional analysis and informal urban settlements: A proposition for a new institutionalist grounded property rights perspective. *Land Use Policy*, *134*, 106906. https://doi.org/10.1016/j.landusepol.2023.106906.

Ngcobo, N., Akinradewo, O., & Mokoena, P. (2024). Challenges to sustainable transport infrastructure integration in Johannesburg, South Africa. *Journal of Sustainable Development of Transport and Logistics*, *9*(2), 92–108. https://doi.org/10.14254/jsdtl.2024.9-2.7

Oláh, J., Khan, K.A., Akhtar, M.A., & Chuluunbaatar, E. (2024). Take a ride on the green side: E-vehicle purchase intentions in the emerging economy context. *Economics and Sociology*, *17*(3), 267-290. doi:10.14254/2071-789X.2024/17-3/14

Peng, Z., Lu, W., Hao, T., Tang, X., Huang, J., & Webster, C. (2023). Cost-aware generative design for urban 'cool spots': A random forest-principal component analysis-augmented combinatorial optimization approach. *Energy and Buildings*, *295*, 113317. https://doi.org/10.1016/j.enbuild.2023.113317.

Pinto, F., & Akhavan, M. (2022). Scenarios for a Post-Pandemic City: Urban planning strategies and challenges of making "Milan 15-minutes city". *Transportation Research Procedia*, *60*, 370–377. https://doi.org/10.1016/j.trpro.2021.12.048.

Pozoukidou, G., & Chatziyiannaki, Z. (2021). 15-Minute City: Decomposing the New Urban Planning Eutopia. *Sustainability, 13*(2), 928. https://doi.org/10.3390/su13020928.

Puppim de Oliveira, J. A., Bellezoni, R. A., Shih, W., & Bayulken, B. (2022) Innovations in Urban Green and Blue Infrastructure: Tackling local and global challenges in cities. *Journal of Cleaner Production*, *362*, 132355. https://doi.org/10.1016/j.jclepro.2022.132355.

Rafieian, M., & Kianfar, A. (2023). Gaps in urban planning: A systematic review of policy-making in the informality of urban space. *Habitat International*, *142*, 102962. https://doi.org/10.1016/j.habitatint.2023.102962.

Savanevičienė, A., Salickaitė-Žukauskienė, R., Šilingienė, V., & Bilan, S. (2022). Ensuring sustainable human resource management during the COVID-19 pandemic: The case of Lithuanian catering organisations. *Economics and sociology*., 15(3), 121-142.

Shi, L., Wang, Y., & Jing, L. (2024). Low-carbon city pilot, external governance, and green innovation. *Finance Research Letters*, *67*(Part B), 105768. https://doi.org/10.1016/j.frl.2024.105768.

Shtjefni, D., Ulpiani, G., Vetters, N., Koukoufikis, G., & Bertoldi, P. (2024). Governing climate neutrality transitions at the urban level: A European perspective. *Cities*, *148*, 104883. https://doi.org/10.1016/j.cities.2024.104883.

Spiliotopoulou, M., & Roseland, M. (2020). Urban Sustainability: From Theory Influences to Practical Agendas. *Sustainability*, *12*(18), 7245. https://doi.org/10.3390/su12187245.

Štreimikienė, D., Mikalauskienė, A., & Macijauskaitė – Daunaravičienė, U. (2022). Role of information management in implementing the Green Deal in the EU and the US. *Journal of International Studies*, *15*(4), 9-27. doi:10.14254/20718330.2022/15-4/1

Sutthichaimethee, P., Mentel, G., Voloshyn, V., Mishchuk, H., & Bilan, Y. (2024). Modeling the Efficiency of Resource Consumption Management in Construction Under Sustainability Policy: Enriching the DSEM-ARIMA Model. *Sustainability*, *16* (24), 10945. https://doi.org/10.3390/su162410945

Wang, H., Zhang, M., & Zhong, M. (2019). Opportunities and challenges for the construction of a smart city geo-spatial framework in a small urban area in central China. *Smart Cities*, 245–258. https://doi.org/10.3390/smartcities2020016.

Wang, J., Li, G., Lu, H., & Wu, Z. (2024). Urban models: Progress and perspective. *Sustainable Futures*, *7*, 100181. https://doi.org/10.1016/j.sftr.2024.100181.

Wolch, J. R., Byrne, J., & Newell, J. P. (2014). Urban green space, public health, and environmental justice: The challenge of making cities "just green enough", *Landscape and Urban Planning*, *125*, 234–244. https://doi.org/10.1016/j.landurbplan.2014.01.017.

Zhang, M., Tan, S., Liang, J., Zhang, C., & Chen, E. (2024). Predicting the impacts of urban development on urban thermal environment using machine learning algorithms in Nanjing, China. *Journal of Environmental Management*, *356*, 120560. https://doi.org/10.1016/j.jenvman.2024.120560.

Zhao, P. & Wan, J. (2020). Examining the effects of neighbourhood design on walking in growing megacity. *Transportation Research Part D: Transport and Environment*, *86*, 102417. https://doi.org/10.1016/j.trd.2020.102417.