










# “Cluster analysis of the capitals of European countries by the “green” image indicators in the context of sustainable development”

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# CLUSTER ANALYSIS OF THE CAPITALS OF EUROPEAN COUNTRIES BY THE "GREEN" IMAGE INDICATORS IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

## Abstract

Ongoing urbanization presents significant environmental challenges, which can be addressed through targeted investments in green infrastructure. Such investments not only mitigate ecological impacts but also enhance a city's brand value and attractiveness to investors and residents. This study evaluates how green infrastructure, along with environmental, social, and economic indicators, influences the formation of a "green" image of the capitals of European countries. The "green" image is conceptualized as the perception of a city as environmentally friendly and sustainable, increasing its appeal to various stakeholders. Using k-means cluster analysis based on 10 indicators across 29 capitals of European countries, four distinct clusters were identified according to their potential for sustainable development. The second Cluster (Berlin, Helsinki, Ljubljana, Madrid, Riga, Sofia, Tallinn, Vilnius, and Zagreb) showed the strongest "green" image, with extensive green areas and low pollution levels balanced by solid socio-economic indicators. The first Cluster (London, Luxembourg, and Paris) had a high quality of life but relatively limited green space. The third Cluster (Amsterdam, Copenhagen, Dublin, Lisbon, Prague, Rome, Stockholm, and Vienna) combined high living costs and life expectancy with moderate green coverage. Most remaining cities, including Athens, Brussels, and Kyiv, were placed in the fourth Cluster, indicating a need for more robust environmental policies. The findings highlight that expanding green spaces, maintaining low pollution levels, and supporting high life expectancy is key to enhancing a city's green image, thereby boosting its investment appeal and overall quality of life.

## Keywords

sustainable development, "green" image, "green" urban areas, "green" infrastructure, European green policy, "green" investments, "green" economy, cluster analysis

## JEL Classification

Q56, R11, R52

## INTRODUCTION

One of the greatest issues of the modern world is the global environmental crisis. Its consequences have become the main reason for the introduction of the European green policy in 2019 (EU, n.d.). The primary objectives of this policy are achieving ecological stability in Europe by 2050, economic recovery from the aftermath of the crisis, poverty reduction, and making the European economy environment-friendly. The European Climate Law and The CHG Footprint Reduction Law, both of which were adopted in 2021, allowed the development of the "Fit for 55" package, which is designed to reduce the European Union's greenhouse gas emissions by 55% by 2030 and includes the mechanisms suitable to combat the climate changes and related energy, transport, land utilization, and taxation problems. In

addition, the EU has developed the EU's biodiversity strategy for 2030, EU forest strategy for 2030, EU's plastics strategy, Soil strategy, Environment action program for 2030, and Zero pollution action plan for air, water, and soil as part of the European Green Deal, a new circular action plan to facilitate the transition to a climate-neutral, resource-efficient economy, recognizing that human well-being and prosperity depend on healthy ecosystems (EU, n.d.).

The environmental crisis and its consequences have the highest influence on cities and their ecosystems. This is because the cities consume 70% of light energy while being responsible for 80% of greenhouse gas emissions (World Resources Institute & Ross Center, 2023). In addition, the populace of these cities, including the capitals, keeps on growing (World Bank Group, n.d.). This results in an overall reduction of the environmental quality. With the introduction of a new program in 2016, the UN has defined sustainable urban development as the most important step in achieving the Millennium Development Goals (UN-Habitat, 2022). This sustainable development revolves around the development of rural communes capable of satisfying the needs of the modern generation without depriving future generations of the same capability (Panchyshyn & Vdovyn, 2023). The prolonged urbanization is connected with numerous environmental drawbacks, including air pollution, high levels of noise, and general reduction of recreational space (Orak et al., 2015). By complying with the UN Global Compact Cities Programme (UN Global Compact, n.d.) and the established European green policy (EU, n.d.), the European countries attempt to combat the aforementioned drawbacks by investing in environment-friendly projects, such as the development of "green" infrastructure, implementation of "green" construction, "green" transport, expansion of "green" municipal areas, etc. In addition, they attempt to maximize the co-benefits, such as increasing brand value and publicity capital. The aforementioned co-benefits play an important role in the global economy and act as an essential financial resource (Panteleychuk, 2009) since they are capable of increasing the volume of investments, migration flow, competitive power of the specified city, quality of life, and the ability to combat eco risks. This is why image capital may become the key economic mechanism to ensure the goals of long-term sustainable urban development under conditions of high social and economic risks.

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## 1. LITERATURE REVIEW

The role of cities in achieving the global sustainable development goals is defined by The Global Goals (n.d.), whereas the main aim is to "make the cities and urban settlements more inclusive, safe, stable and integral." However, there is still no unified approach toward implementing sustainable development. Some researchers (Battisti et al., 2023; ITU, 2016; Krasnikova et al., 2021; Stukalo et al., 2018) dedicate their scientific works to developing an integrated approach to explaining and implementing municipal sustainable development. In contrast, others (Ruá et al., 2021; Smirnova & Privarnikova, 2015; Al-Nasrawi et al., 2017; Russo et al., 2016; Al-Nasrawi et al., 2015; Oetomo & Santoso, 2023) study only certain aspects of the aforementioned municipal sustainable development.

For example, ITU (2016) claimed that the primary components of a city with sustainable de-

velopment are its capability to generate income and provide employment to the local population. Another critical aspect is the capabilities to satisfy the primary needs of the local population (including safety, health care, education, etc.) regardless of their race, gender, or wealth, protect and maintain the ecologic balance, and ensure the reign of democracy, social justice, and stability. Battisti et al. (2023) believe that the end goal of municipal sustainable development is to ensure the prosperity of the citizens based on a healthy municipal ecosystem. The effective functioning of such an ecosystem revolves around its integration with other aspects of municipal management (Battisti et al., 2023).

There are also numerous suggestions related to steady urbanization. For instance, certain researchers suggest renovating old or otherwise vulnerable buildings as a part of sustainable development (Ruá et al., 2021). Others propose the implementation of IT into the entire municipal infrastructure to create

“smart” cities (Smirnova & Privarnikova, 2015; Al-Nasrawi et al., 2017; Russo et al., 2016; Al-Nasrawi et al., 2015; Oetomo & Santoso, 2023), while some devote their attention to the development of social infrastructure (Razumkov-centre, 2021). All of the aforementioned articles, however, view the green space expansion alongside the creation of new recreational zones as a factor of an indirect influence, which allows to maintain the quality of life in cities (Orak, 2015; Smirnova & Privarnikova, 2015; Kosyk & Letik, 2021) and reduces the influence of a greenhouse effect (EC, n.d.; Russo et al., 2016; Al-Nasrawi, 2015). Battisti et al. (2023) suggest that apart from the ecologic, economic, and social functions, the green urban zones also have cultural, historical, and city-forming functions, giving different cities their own unique and representative identity.

Green urban zones are defined as pivotal factors in shaping the municipal landscape, allowing for a better understanding of their role in creating an attractive municipal green space. This space is an influential element of any city and a great way to support the local residents’ physical and mental well-being. Finally, it also positively affects the municipal image (Battisti et al., 2023). Rodríguez Romero et al. (2017) arrived to the same conclusion. They claim that historically developed green areas and their connection to historical landmarks are crucial for the cultural development of every municipal image, which makes the city distinct and recognizable while retaining and preserving its cultural and historical value.

Currently, the scientific discourse regarding the opportunity to capitalize on this “green” image is not well-developed. These capitalization opportunities mostly revolve around the development of new “green” brands capable of fulfilling the role of the global “nodes of attraction” not only for new investments but also for intellectual assets and labor forces.

There are also no practical methods of rating the countries according to different indicators regarding their attractiveness for “green” investments. For instance, the existing UN rating “Sustainable development,” created by the Bertelsmann Foundation and Cambridge University (Sachs et al., 2023), focuses solely on how different countries reach the defined sustainable development

goals and how it affects the nation’s well-being. However, the aforementioned aspects of “green” development, including the development of “green” infrastructure, remain outside of this focus. In addition, this rating evaluates the entire country without considering different territorial attributes.

The Global Liveability Ranking uses different evaluation methods. The overall rating is defined according to six indicators: stability, healthcare, culture, environment, education, and infrastructure (EIU, 2023). Even though there is a criterion such as “environment,” it assesses only the emissions per capita without considering the development of green space. This index also evaluates the city’s attractiveness only in terms of migration, leaving the investment attractiveness outside the main focus and evaluating it only indirectly.

The economic power is evaluated by the Global Competitiveness Index, which is based on the analysis of the competitive ability of different countries (WEF, 2020). The index itself utilizes the methodology of the World Economic Forum and has the following twelve pillars of competitiveness:

- Institutions;
- Appropriate infrastructure;
- Stable macroeconomic framework;
- Good health and primary education;
- Higher education and training;
- Efficient goods markets;
- Efficient labor markets;
- Developed financial markets;
- Ability to harness existing technology;
- Market size – both domestic and international;
- Production of new and different goods using the most sophisticated production processes;
- Innovation.

These twelve pillars are divided into three groups: basic conditions for development, amplifying factors, and innovative factors. Still, this index does not define “green” development as the pillar of competitiveness and does not consider the internal territorial disparity of each specific country.

The importance of complying with the European green policy and following the Sustainable Development Goals on both the regional and local levels, where the most resources are consumed

while the communities and new enterprises develop, proves the necessity to divide the country's territory depending on how well the aforementioned policy is implemented and how many of the aforementioned goals are achieved. The investment assets in the modern information society greatly depend on the territorial image (that of an entire country, region, or city). The image itself serves as the foundation of the national country's brand and thus affects its investment, migration, and tourist attractiveness. Overall, numerous factors influence the territorial image, including the attractiveness for tourists and business people, comfortable living and working conditions, as well as natural beauty affected by the number of green zones. However, the modern tendency to reduce urban green space (Ocheretnyi et al., 2017) and growing urbanization-related issues threaten to deprive certain capitals of their positive "green" image that serves as the primary foundation for implementing the sustainable development strategy and achieving the corresponding goals.

Dividing cities into clusters according to their "green" image is important from both a scientific and practical standpoint. Scientifically, the methodology can be expanded and a broader dimensional analysis carried out. In practice, the rating system for evaluating economic and social attractiveness can be improved.

The purpose of this paper is to evaluate the influence of green infrastructure and related ecological, social, and economic factors on the formation of the "green" image of the capitals of European countries and to classify these cities according to their potential for sustainable urban development using k-means clustering.

## 2. METHODOLOGY

This study examined the relationship between urban green infrastructure and the development of a green territorial image in 29 European capitals (27 EU Member States, London (the UK), and Kyiv (Ukraine)). The choice of European capitals was driven by their advantages in terms of high urban population density and the availability of comprehensive environmental and socio-economic data from geographically diverse locations. A dataset

was compiled, including 10 indicators, which were selected based on the criterion of comprehensive coverage of environmental and socio-economic factors that form a sustainable urban model and an attractive green image of urban areas. The main data sources were the European Environment Agency (EEA) and Numbeo (n.d.a, n.d.b). Specific indicators included area of urban green spaces (km<sup>2</sup>), availability of street trees (km<sup>2</sup>), natural and semi-natural areas (km<sup>2</sup>), recreational and sports areas (km<sup>2</sup>), private gardens (km<sup>2</sup>), high nature value agricultural land (km<sup>2</sup>), water and wetlands (km<sup>2</sup>), average cost of housing (euro/m<sup>2</sup>) average life expectancy (years), pollution index (dimensionless). To allow comparison between cities of different sizes, each of the first seven environmental indicators (measured in km<sup>2</sup> or linear kilometers) was normalized by dividing it by the total area of the respective city (km<sup>2</sup>), resulting in a proportion. The remaining socio-economic indicators (average cost of housing, average life expectancy, and pollution index) were used in their original units.

Pearson correlation coefficients ( $\rho$ ) were calculated to examine the linear relationships between the average cost of housing, average life expectancy, and city pollution index using an aggregated dataset of 29 metropolitan cities. Scatter plots were created to visually represent these correlations. K-means clustering was used to identify distinct groups of cities based on the full set of 10 normalized variables. The purpose of the cluster analysis in this study is to identify typical groups of European capitals that share similar combinations of environmental, social, and economic indicators, enabling a comprehensive assessment of their "green" image. This approach allows for the analysis of cities not only through individual indicators but also in terms of the overall structure of interrelationships among them. The number of clusters ( $k$ ) was set to 4, and the algorithm was initialized using the k-means++ method to optimize centroid placement. For each of the four resulting clusters, descriptive statistics (mean and standard deviation) were calculated for all 10 variables. This analysis aimed to describe the key characteristics of each Cluster and assess intracluster variability. Clustering helps reveal hidden patterns and factor combinations that contribute to a stronger or weaker "green" image, which may remain unnoticed when examining indicators separately.

### 3. RESULTS AND DISCUSSION

Territorial image is a stable associational idea or opinion about a specific territory. It is primarily influenced by the historical development and opinions of different groups of people and reflects the attributes of a certain territory, affecting its competitiveness and satisfaction of the people's wants, business, and state on a particular territory (Iakovenko et al., 2023; Zinchenko, 2018).

Territorial image is a complicated definition since it also affects the conditions to ensure the satisfaction of wants of the people, for example, when the quality of life is high. However, ensuring the aforementioned conditions often requires investments in the development, promotion, and implementation of resource-saving technologies, as well as eco-friendly projects and programs based on the concepts of environmentalism. Doing so allows one to maintain the appropriate competitive image of a certain territory (Zinchenko, 2018). Thus, a territorial image associated with the "green" economy becomes a "green" image. This results in establishing a strong connection between economic growth and ecologic stability. Moreover, this "green" image increases the attractiveness of a particular territory as a place for comfortable work and living, a hotspot for tourists, or provides a good opportunity for the stakeholders to invest in different "green" projects, such as "green" infrastructure or tourist facilities. The "green" image of a territory refers to the perception and reputation of a geographical area as environmentally friendly, sustainable, and committed to ecological values. It encompasses the region's visible efforts in green infrastructure, renewable energy, sustainable urban planning, and environmental protection, contributing to its attractiveness for residents, tourists, and investors.

The value of green space and the way it affects the state of different territories are the main foundations of the "green" image of different cities in European countries. Most of these cities inherited their green space from the past or appeared as a result of the new environmental policy. The "green" image dramatically affects the city's first impression, specifically about its living conditions and tourism potential. These two attributes affect investment attractiveness. Accordingly, the cities

of European countries with high population were chosen to better represent the diversity in geographical settings and the number of urban green zones in the analysis. The highest rate of urban population is always in the capital cities (World Bank Group, n.d.). Thus, 29 capitals of European countries were chosen for the analysis. Out of these cities, 27 are the capitals of the EU countries, while the other two are the capital of Great Britain – London, and the capital of Ukraine – Kyiv.

A unique set of indicators was developed to establish the connection between the sustainable development of cities of European countries and their current "green" image. The similarities in terms of these 10 indicators were used as the foundation for evaluating the potential of the capitals of European countries in terms of development of the "green" image (Figure 1).

Green space is an important element of the municipal economy in terms of developing a "green" image since it provides many ecological and aesthetic advantages. Thus, the total size of green space and the total size of recreational areas were defined as the indicators for evaluation. Table 1 explains these indicators in detail.

The value of each indicator varies depending on the total area of each capital and ranges from 26% to 89% (Figure 2). It was found that Berlin has one of the most developed green spaces among all of the researched capitals, with a total of 9457.9 sq. km., which is 54% of the total area. Valletta follows Berlin with its green space equaling 31% of the total area of the capital. The most developed green space is in Zagreb, which has a total area of 89% of the total size of the capital.

The average cost of accommodation and life expectancy of each analyzed capital were used to evaluate the social and economic influence. Earlier research, for example, Barboza et al. (2021), proved that the aforementioned indicators indeed influence the "green" image. The following capitals, such as Athens, Brussels, Budapest, Copenhagen, and Riga, have higher death rates due to the lack of green zones (Barboza et al., 2021). The higher death rates would have possibly been avoided if the aforementioned countries had followed the WHO recommendations to increase the number of mu-

Indicator	Characteristics	Unit of measurement
Green urban areas	Area of green spaces of the city	km <sup>2</sup>
Trees (street trees, isolated patches)	Area planted with trees	km <sup>2</sup>
Natural and semi-natural	Green areas of undeveloped land with limited or no maintenance	km <sup>2</sup>
Sport and leisure	Area for sports and recreation	km <sup>2</sup>
Private gardens	Private green areas	km <sup>2</sup>
HNV farmland	The area of agricultural land	km <sup>2</sup>
Water and Wetlands	The area of prominent wetlands	km <sup>2</sup>
Housing price per 1 sq.m.	Average cost of housing	Euro/m <sup>2</sup>
Average life expectancy	Average life expectancy	years
Pollution index	City pollution index	km <sup>2</sup>

Figure 1. Key points of the research

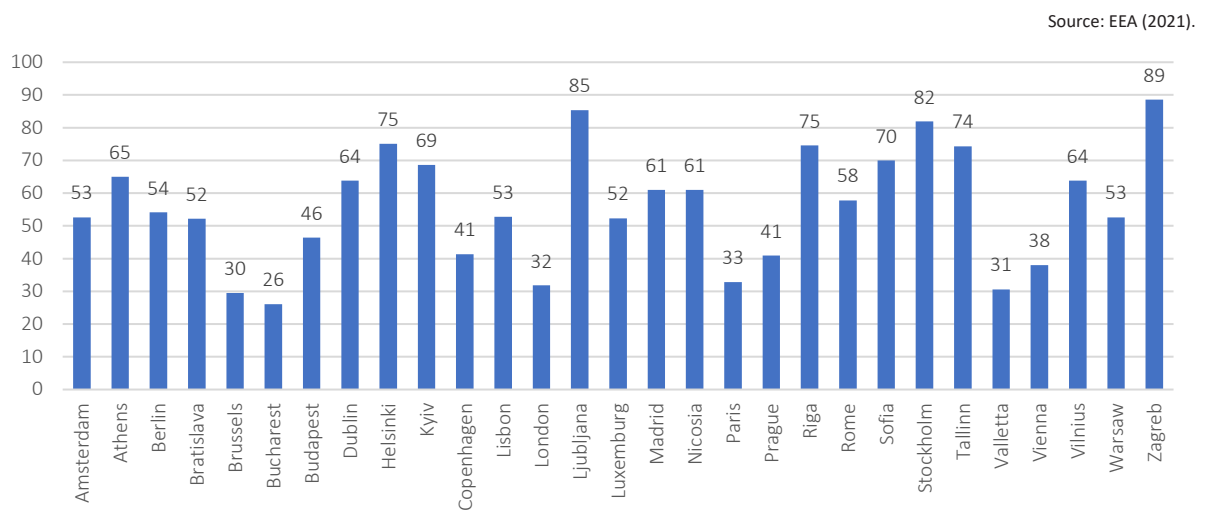


Figure 2. The share of green infrastructure in the total area of some capitals of European countries, %

**Table 1.** Key indicators of the “green” image development in the researched capitals

Source: EEA (2021), Numbeo (n.d.a, n.d.b).

No.	City	Square in km <sup>2</sup>						
		Green urban areas	Trees	Natural and semi-natural	Sport and leisure	Private gardens	HNV farmland	Water and Wetlands
1	Amsterdam	142.5	142.5	374.0	89.0	118.7	682.7	1567.2
2	Athens	75.1	82.0	3,524.9	20.5	314.2	259.6	170.8
3	Berlin	288.5	1,410.7	12,567.8	192.4	513.0	1,442.7	833.6
4	Bratislava	18.1	112.4	1,512.5	21.8	43.5	101.6	72.5
5	Brussels	58.8	218.7	336.2	22.8	290.5	22.8	13.1
6	Bucharest	17.1	67.6	958.9	2.9	10.5	21.9	25.7
7	Budapest	90.5	432.3	2,362.4	90.5	181.0	1,206.3	211.1
8	Dublin	82.6	394.7	4,149.2	202.0	55.1	615.0	339.6
9	Helsinki	138.6	4,283.1	6,500.2	88.2	579.5	806.2	932.2
10	Kyiv	77.3	137.7	333.6	1.7	5.3	0.0	10.0
11	Copenhagen	114.3	212.2	702.1	77.6	183.7	53.1	330.6
12	Lisbon	62.9	338.1	2,830.3	39.3	204.4	676.1	314.5
13	London	331.4	338.9	738.0	308.8	474.4	97.9	97.9
14	Ljubljana	20.3	148.7	4,142.6	13.5	175.7	1,257.0	20.3
15	Luxembourg	18.4	161.0	1,748.4	18.4	50.6	391.1	23.0
16	Madrid	341.8	618.5	5,892.1	81.4	325.5	2,555.4	97.7
17	Nicosia	10.1	63.8	1,444.9	3.4	47.0	477.2	6.7
18	Paris	28.0	50.7	284.3	16.0	44.1	2.7	12.0
19	Prague	118.7	419.6	2,089.9	47.5	102.9	364.1	95.0
20	Riga	77.8	622.7	9,230.9	62.3	451.4	295.8	871.7
21	Rome	96.7	1,438.2	3,601.5	60.4	749.3	821.8	205.5
22	Sofia	67.8	461.1	5,790.7	13.6	271.2	2,739.4	135.6
23	Stockholm	11.5	18.6	466.4	8.9	55.0	21.3	144.5
24	Tallinn	55.3	486.7	6,294.3	0.0	298.7	453.5	619.5
25	Valletta	1.9	6.8	42.4	1.9	7.3	7.1	15.7
26	Vienna	94.5	248.2	2,670.9	47.3	200.9	886.4	307.3
27	Vilnius	82.6	394.7	4,149.2	18.4	202.0	615.0	339.6
28	Warsaw	92.1	1,489.3	4,114.8	61.4	291.7	1,781.0	230.3
29	Zagreb	45.6	228.0	6,777.8	0.0	547.1	5,698.9	136.8

municipal green zones in the EU cities (Barboza et al., 2021). The pollution rate of the cities was evaluated according to data from Numbeo (n.d.a). The main indicators are air, water, light, and noise pollution rates, development of waste disposal, number of green zones, overall cleanness of the municipal territory, and living conditions. This value is an inversely proportional quantity. The highest possible value is 100, which indicates the highest pollution rate. The detailed analysis of a correlation between the life expectancy plus the average cost of accommodation and the pollution rate of each of the analyzed capitals is shown in Figures 3 and 4.

According to the European Environment Agency (EEA), despite the general reduction of the emission rates in the EU countries throughout 2005–2020, air pollution remains a major risk factor for human health. In 2020, 96% of the urban popula-

tion in the EU was negatively affected by air pollution at a much higher rate than that established by the WHO as acceptable (EEA, 2022). The relationship between these two values in the analyzed capitals was determined by analyzing the correlation between life expectancy and the pollution rate (Figure 3). This relationship is most salient in such capitals as Amsterdam, Budapest, Bucharest, Helsinki, Kyiv, Copenhagen, Lisbon, Ljubljana, Luxembourg, Stockholm, Tallinn, and Vienna. Another important factor of influence on the “green” image is the average cost of accommodation. An inverse relationship exists between this indicator and the pollution rate (Figure 4).

Based on the analysis, an increase in the average cost of accommodation and life expectancy combined with the reduction of air pollution rate and expansion of green space can be defined as the

Source: Numbeo (n.d.a, n.d.b).

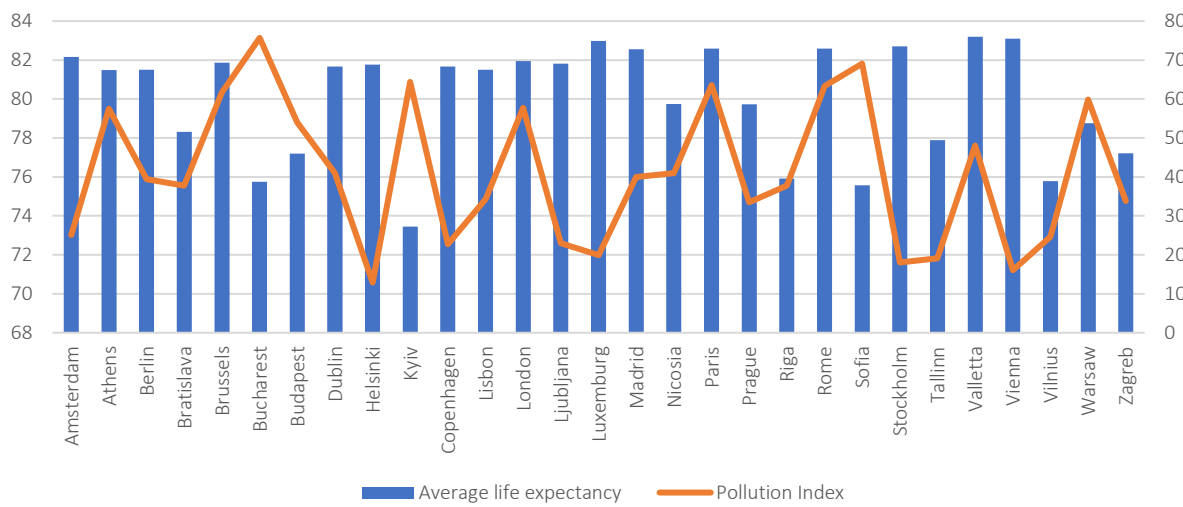


Figure 3. Correlation between the life expectancy and the pollution rate

Source: Numbeo (n.d.a, n.d.b).

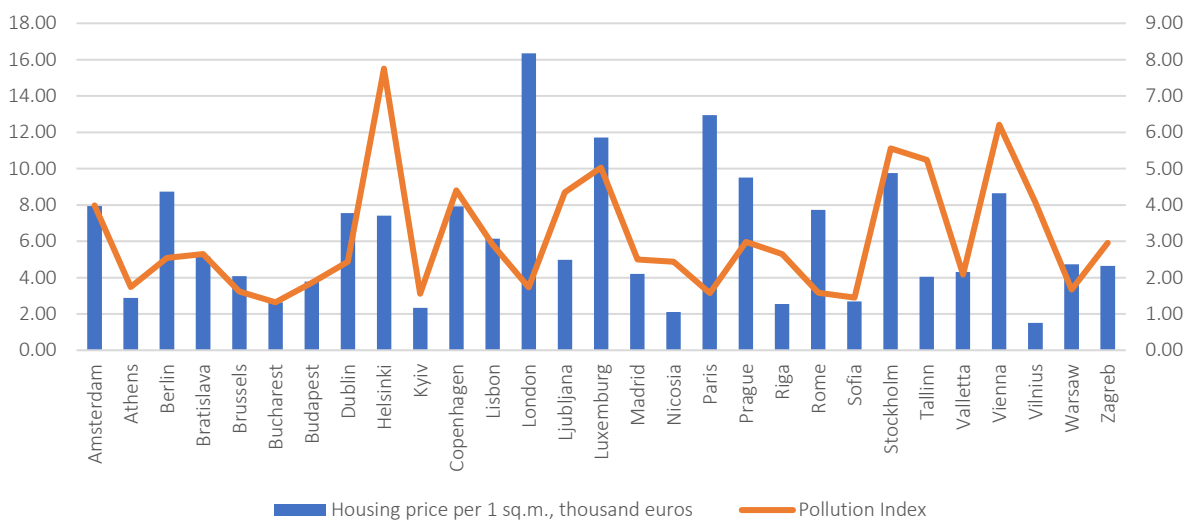


Figure 4. Correlation between the average cost of accommodation and the pollution rate

factors that influence the “green” image. The analyzed capitals were divided by utilizing the k-means clustering to prove theoretical assumptions. This made it possible for the cities to be categorized according to their territorial attributes, ecological and social conditions, and economic potential regarding eco-friendliness. These factors are seen as providing an opportunity for a better understanding of each city’s potential regarding the development of a “green” image. The peculiarities of the analyzed data with different measurement values and heterogeneous attributes can explain the choice of the aforementioned method.

By applying k-means clustering, the underlying structure of the data can be identified, the dataset can be segmented, the dimensionality of the data can be reduced, and potential anomalies can be detected. The applied k-means clustering is characterized by the use of 10 variables (Table 1). The more variables there are, the harder it is to divide the objects according to these variables, thus making it more difficult to define the structure of a cluster. However, this number is appropriate for the case under study. The number of observations (capitals) is 29. This number is rather small for proper clustering. The fewer observations, the less data to define the structure of a cluster. However,

the lack of observations is balanced by the number of variables, which allows the structure of a cluster to be better defined.

Thus, a total of four clusters were acquired. This number can be explained either by the real data structure or as the result of the “retraining” of the algorithm due to the limited number of observations. Ten similarity measures were chosen, but the utilized algorithm used only three of them. Three similarity measures is a small number to define the general similarity. Nevertheless, the attributes of the selection, particularly the index values, made it possible for the general similarity to be defined in the end. After the initial setup and data processing, four clusters were acquired and analyzed. It is necessary to note that each Cluster’s analysis should be evaluated only in comparison with the other clusters.

The first Cluster contains the following cities (Table 2): Paris (316,6205), London (858,7402), and Luxembourg (679,4844). The analysis identified the following similarities between these capitals. The average values of such factors as “Green urban areas,” “Water and Wetlands,” and “Sport and leisure” are lower than the average mean. The value of the factor “Trees (street trees, isolated patches)” is higher than the average mean of Cluster 1, while the factor “HNV farmland” is nearing the average mean.

The factors “Natural and semi-natural” and “Private gardens” have much higher upward deviation from the average mean. It can be concluded that these cities have a significantly higher number of natural and semi-natural zones and gardens

compared to the others. The following two factors had a major influence on the creation of Cluster 1: “Housing price per 1 sq.m.” and “Average life expectancy.” This is explained by their higher upward deviation from the average mean. It also shows that London, Paris, and Luxembourg have the highest accommodation costs compared to the other capitals while simultaneously possessing a higher quality of life. “Pollution index” has an average value lower than the average mean, which is explained by its connection to the other evaluated factors. The evaluated factors illustrate the overall situation in the capitals from Cluster 1. These cities have a high number and area of green zones, high accommodation costs, high number of gardens, average life expectancy, and low pollution rate.

Cluster 2 includes the following capitals: Zagreb (1242,402), Berlin (20001,696), Sofia (962,984), Tallinn (724,670), Helsinki (1372,449), Riga (1074,629) and Madrid (643,712) (Table 3). The percentage of green infrastructure in these capitals varies from 54.1 to 88.6%.

The values of factors such as “Natural and semi-natural,” “HNV farmland,” “Trees (street trees, isolated patches),” “Private gardens,” and “Water and Wetlands” are very high within Cluster 2, which indicates that the analyzed cities have the potential for developing a good “green” image. This is also confirmed by the fact that the factor “Green urban areas” is nearing the average mean. In terms of investment attractiveness, there are minor deviations from the average mean in such factors as “Housing price per 1 sq.m.” and “Average

**Table 2.** Attributes of Cluster 1

Source: Created based on the data from Statistica.

Variable	Descriptive Statistics for Cluster 1 The Cluster contains 3 cases		
	Mean	Standard Deviation	Variance
Green urban areas	125.93	177.969	31,673
Trees (street trees, isolated patches)	183.55	145.394	21,139
Natural and semi-natural	923.58	749.456	561,684
Sport and leisure	114.40	168.333	28,336
Private gardens	189.70	246.615	60,819
HNV farmland	163.89	202.441	40,982
Water and Wetlands	44.31	46.738	2,184
Housing price per 1 sq.m.	13,664.63	2,397.818	5,749,531
Average life expectancy	82.50	0.525	0
Pollution index, max. 100, the less, the better	47.07	23.711	562

**Table 3.** Attributes of Cluster 2

Source: Created based on the data from Statistica.

Variable	Descriptive Statistics for Cluster 2 The Cluster contains 7 cases		
	Mean	Standard Deviation	Variance
Green urban areas	145.066	120.953	14630
Trees (street trees, isolated patches)	1158.669	1426.468	2034812
Natural and semi-natural	7579.122	2487.181	6186071
Sport and leisure	62.536	68.421	4681
Private gardens	426.628	126.942	16114
HNV farmland	1998.849	1895.975	3594721
Water and Wetlands	518.145	381.839	145801
Housing price per 1 sq.m.	4897.699	2330.003	5428914
Average life expectancy	78.914	2.950	9
Pollution index, max. 100, the less, the better	36.014	18.030	325

life expectancy.” The average life expectancy in the analyzed cities is 80 years, corresponding with the average mean of the entire set of clusters. The pollution index has the lowest value, thus indicating that these cities have lower pollution rates compared to the other capitals. Overall, the acquired results allow it to be concluded that the capitals in Cluster 2 are characterized by a large number of green areas, average accommodation costs and life expectancy, and the lowest pollution rate, along with a slightly lower number of recreational and sports zones compared to other clusters.

Cluster 3 consists of Copenhagen (479,1271), Vienna (271,6603), Prague (447,2935), Rome (624,8226), Amsterdam (670,7193), Lisbon (679,8217), Dublin (675,3918) and Stockholm (759,9277) (Table 4). All of these capitals have very low pollution index. However, despite the implementation of sustainable development, the continuous growth of the urban population and the

development of tourism negatively impact some of these capitals, thus lowering their potential for the development of the “green” image. In addition, such factors as “Green urban areas,” “Trees (street trees, isolated patches),” “Private gardens,” and “Water and Wetlands” have a value below average. Overall, the capitals in Cluster 3 are characterized by a lower number of green zones, trees, natural and semi-natural territories, recreational and sports zones, private gardens, and wetlands. The living costs, however, are very high. It can be explained by the fact that, over time, these cities have been transformed into modern centers of industry, technology, and innovation. This also provides them an excellent foundation for the future development of “green” technologies, making it possible to make their economy more innovative and attractive to investors.

Most of the analyzed capitals ended in Cluster 4 (Table 5). This Cluster includes Brussels (606,2242),

**Table 4.** Attributes of Cluster 3

Source: Created based on the data from Statistica.

Variable	Descriptive Statistics for Cluster 3 The Cluster contains 8 cases		
	Mean	Standard Deviation	Variance
Green urban areas	90.472	39.964	1597
Trees (street trees, isolated patches)	401.506	439.494	193155
Natural and semi-natural	2110.539	1459.651	2130582
Sport and leisure	71.491	58.073	3372
Private gardens	208.749	226.610	51352
HNV farmland	515.065	332.960	110862
Water and Wetlands	413.024	475.311	225921
Housing price per 1 sq.m.	8150.154	1157.305	1339355
Average life expectancy	81.886	1.041	1
Pollution index, max. 100, the less, the better	31.750	15.356	236

Athens (510,8225), Warsaw (934,3902), Nicosia (493,6324), Budapest (258,0396), Valletta (721,3908), Bratislava (571,5926), Bucharest (483,4688), Ljubljana (835,5798), Kyiv (687,4407) and Vilnius (913,4066).

Green urban areas comprise only 1.8% of the total urban area in the analyzed cities. The only exception is Kyiv, which has 9.21% of green urban areas. The overall value of the factor “Green urban areas” is much lower than that of the other Clusters.

Factors “Trees (street trees, isolated patches),” “Private gardens,” “HNV farmland,” “Water and Wetlands,” and “Sport and leisure” have below average values. Factor “Natural and semi-natural” is slightly above average, indicating that there are natural and semi-natural territories within the analyzed cities, though not as large as in the previously analyzed Cluster. Factor “Housing price per 1 sq.m.” has a much lower value compared to Clusters 1 and 3. It can be concluded that the accommodation cost is significantly lower in the analyzed capitals from Cluster 4. The value of the factor “Average life expectancy” is slightly below the average mean, but the pollution index is higher, indicating that these cities are more polluted compared to the previously analyzed.

Overall, Cluster 4 has a lower number of green zones, trees, private gardens, and wetlands. The number of natural territories, however, is high, with lower accommodation costs and average life expectancy. Compared to other Clusters, the pollution rate is higher as well. The only exceptions are Vilnius and Ljubljana. These capitals focus their

economy on sustainable development goals. In addition, Ljubljana is the only capital with a “zero waste” status (Zero Waste Europe, 2019). The case of Kyiv warrants particular attention. Although the city reports the highest share of green urban areas among the cities in Cluster 4 (9.21%), the impact of geopolitical factors on its environmental profile must be considered. Due to the full-scale war in Ukraine, which began in 2022, the process of shaping the capital’s “green” image has been effectively halted. Even prior to the war, Kyiv’s environmental policy exhibited relative weaknesses. However, the ongoing hostilities have introduced new and urgent challenges – including pollution from military activities, damage to infrastructure, and the loss of green spaces. Now, these issues surpass pre-war environmental concerns in terms of their immediacy and severity.

The general analysis of the conducted clustering (Table 6) indicates that each of the defined Clusters has its unique attributes and peculiarities regarding the number of green zones, natural territories, recreational and sports zones, as well as the ecologic situation and quality of life.

According to the analysis, Cluster 1 is considered to have very high potential in terms of the development of the “green” image. More than 30% of the area of the capitals analyzed in Cluster 1 are green zones. These capitals have an innovative policy in terms of sustainable development implementation. They are leaders in developing the “green” infrastructure, implementation and utilization of renewable energy, as well as eco-friendly transport. These factors make these capital cities attractive

**Table 5.** Attributes of Cluster 4

Source: Created based on the data from Statistica.

Variable	Descriptive Statistics for Cluster 4 The Cluster contains 11 cases		
	Mean	Standard Deviation	Variance
Green urban areas	49.447	35.793	1281
Trees (street trees, isolated patches)	286.727	421.103	177328
Natural and semi-natural	2083.853	1645.256	2706868
Sport and leisure	23.515	27.993	784
Private gardens	142.612	123.780	15322
HNV farmland	522.682	623.445	388683
Water and Wetlands	101.443	116.547	13583
Housing price per 1 sq.m.	3498.800	1262.378	1593599
Average life expectancy	78.851	3.095	10
Pollution index, max. 100, the less, the better	49.782	16.681	278

for investments. They also have their unique municipal brand and identity, which is certified by the low pollution rate and high accommodation costs.

**Table 6.** Key conclusions of the conducted k-means clustering

<b>Cluster 1. Paris, London, Luxembourg</b>
Average number of trees and green zones
Large number of natural and semi-natural areas
Average number of recreational and sports zones
Average accommodation costs and life expectancy
Average pollution rate
<b>Cluster 2. Zagreb, Berlin, Sofia, Tallinn, Helsinki, Riga, Madrid, Ljubljana, Vilnius</b>
Large number of trees, green zones and natural areas
Lower number of recreational and sports zones
High accommodation costs and higher life expectancy
Lower pollution rate
<b>Cluster 3. Copenhagen, Vienna, Prague, Rome, Amsterdam, Lisbon, Dublin, Stockholm</b>
Lower number of trees, green zones and private gardens
Average number of natural and semi-natural areas
Lower number of recreational and sports zones
Average accommodation costs and life expectancy
Lower pollution rate
<b>Cluster 4. Brussels, Athens, Warsaw, Nicosia, Budapest, Valencia, Bratislava, Bucharest, Kyiv</b>
Lower number of trees, green zones and natural areas
High number of natural and semi-natural areas
Lower number of recreational and sports zones
Lower accommodation costs and life expectancy
Higher pollution rate

Cluster 2 has the highest potential in terms of the “green” image since it has the highest number of green zones, ranging from 54.1% to 88.6% of the total municipal area and the lowest pollution rate. The capitals from this Cluster are also very attractive to investors and are available as hot spots for international tourists due to their thorough in-

vestment in their economy, ecology, and social development.

Cluster 3 consists of the capitals with the highest accommodation costs, highest life expectancy, and low pollution rate. While their quality of life is high and their municipal identity is noticeable, they have a lower potential for “green” image development due to fewer green zones and areas.

Capitals from Cluster 4 have the highest pollution rate with the lowest number of green areas, thus having the lowest potential in “green” image development. However, the following two capitals – Ljubljana and Vilnius – have been excluded and reassigned to Cluster 2. This decision can be explained by the fact that these capitals demonstrate a sound sustainable development policy, an above-average number of green zones, a below-average pollution rate, and high levels of quality of life and tourist attractiveness.

The clustering outcomes confirm the conclusions of Battisti et al. (2023), who argue that green zones perform ecological, economic, and social functions and contribute to a city’s cultural and symbolic identity, thereby strengthening its municipal brand. The revealed correlation between the extent of green areas and a city’s attractiveness supports the findings of Rodríguez Romero et al. (2017), who emphasize the role of historically embedded green spaces in reinforcing municipal distinctiveness and cultural value. Furthermore, the perspectives of scholars such as Orak et al. (2015) and Kosyk and Letik (2021) are affirmed by this study’s results, particularly in terms of the indirect yet essential contribution of green zones to urban quality of life and climate change mitigation.

## CONCLUSION

The study aims to assess the impact of green infrastructure alongside ecological, social, and economic factors on forming the “green” image of European capitals. These factors are centered around the general increase in the number of green zones. Initially, data on 29 capitals of European countries were analyzed. Subsequently, k-means clustering was applied to determine their potential for “green” image development. For this analysis, 10 indicators were utilized. Based on the obtained results, the 29 capitals were then classified into four distinct clusters. The first Cluster consists of Paris, London, and Luxembourg. The second Cluster includes Zagreb, Berlin, Sofia, Tallinn, Helsinki, Riga, Madrid, Ljubljana, and Vilnius. The third Cluster comprises Copenhagen, Vienna, Prague, Rome, Amsterdam, Lisbon, Dublin, and Stockholm. The fourth Cluster consists of Brussels, Athens, Warsaw, Nicosia,

Budapest, Valletta, Bratislava, Bucharest, and Kyiv. According to the analysis, the highest potential in terms of the development of the “green” image is attributed to the second Cluster. This is certified by the highest volume of green areas, the lowest pollution rate, and very high life quality. The costs of living and accommodation, however, are high as well, but this is a plus in terms of sustainable development since it increases the potential investment attractiveness, which may also draw tourists. More accurate results may be acquired by analyzing the additional factors capable of directly or indirectly influencing the development of the “green” image, such as the attractiveness of international investment and geopolitical conditions, particularly the impact of war in the case of Kyiv.

By applying the clustering method, a better understanding has been gained of the potential for developing a “green” image and making the analyzed capitals more attractive for comfortable living, tourism, green business, innovations, etc. A prominent branch for future research is the influence of the aforementioned “green” image on regional investment attractiveness, which is affected by the presence (or lack thereof) of the “green” business.

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