

Efficiency of urban development: gaps in continental profile

Alin MARICUȚ

Bucharest University of Economic Studies, Bucharest, Romania
alin.maricut@csie.ase.ro

Giani-Ionel GRĂDINARU

Bucharest University of Economic Studies, National Institute of Economy, Romanian Academy,
Bucharest, Romania
giani.gradinaru@csie.ase.ro

Erika MARIN

Bucharest University of Economic Studies, Bucharest, Romania
erika.marin@csie.ase.ro

Valentina VASILE

National Institute of Economy, Romanian Academy, Bucharest, Romania
val.vasile.ien@gmail.com

Abstract. *International authorities such as the European Commission and the United Nations pay special attention to sustainable urban development, for this purpose, strategies such as the European Green Deal or the Sustainable Development Strategy 2030 agenda, SDG 11 Sustainable cities and communities are developed. Urban development represents a fundamental direction in the transition process towards the green economy, a sustainable economic model. The paper aims to identify the degree of efficiency of economic development in the context of sustainable development for 41 cities in Romania, Germany, Japan, United States of America and Australia. To achieve this objective, the Data Envelopment Analysis (DEA) method is used, with the aim of identifying the gaps regarding the sustainability of the analyzed cities. Data Envelopment Analysis allows the evaluation of the efficiency of urban settlements in the sample based on representative variables, selected as input. So, the research is ready to give answer to question like "What are the efficient cities in terms of sustainability?" and "What are the relationships between the cities included in the sample?". The main results showed that there are cities that have a model of sustainable economic development, but certain cities present significant gaps from the point of view of efficient sustainable economic development. In addition, port cities seem to develop an association relationship, with inefficient port cities being associated with efficient port cities.*

Keywords: DEA, urban development, efficiency, sustainability, green economy.

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Introduction

Cities and metropolitan areas are the main contributors to national economies (OECD, 2023). Urban development is a current challenge at the level of public administration. The depopulation of rural areas and the growth of the urban population, especially among large cities, must be carefully monitored. If not analyzed in detail, the exponential growth of the urban population can lead to the creation of economic and social imbalances and can have a negative impact on the environment (European Commission, 2023). Until now, there is no analysis at the level of cities in several states that shows the efficiency of their development in terms of economic growth, but also of reducing the rebound effect. The analysis of the economic development efficiency of urban settlements in close correlation with the reduction of pollution is one of the new elements of this study. In other words, in this research the sustainable development model of the 41 cities in the 5 countries (Romania, United States of America, Germany, Japan and Australia) is analysed.

Therefore, the main objective of this research is to identify cities with an effective model of sustainable development, but also to identify the gaps between them. To achieve these objectives, the Data Envelopment Analysis (DEA) method was used, the efficiency score being calculated based on an "input oriented" type model, since the input variables can be directly influenced by the local administration through public policies.

The work continues with the "Problem statement" chapter, where a review of the specialized literature is carried out, which has the role of reviewing the current state of research in the field. Later, in the section "Aims of the research", the objectives of the paper are detailed. In the "Research Methods" chapter, information is described regarding the variables used, the data source, the selected sample, as well as the analysis methods used in order to produce reliable results that contribute to the achievement of all the objectives of the paper. After the actual analysis, the main results of the study are disseminated in the "Findings" chapter, accompanied by related arguments and explanations. Finally, the paper ends with the conclusions section where the main results are scored, the limits of the research are described and the directions for the further development of the research are identified.

Problem statement

In actual society, the phenomenon of urbanization is increasingly present, many of the big cities reaching the stage of metropolises. This transition from the status of "big city" to "metropolis" is achieved based on the transition of available land in the urban-rural relationship (Chen et al., 2020). This transition generates a series of challenges in terms of local administration, from the perspective of the decision-making process. Li et al. (2022) claim that in such cases, local administrations must focus on industrialization planning with an emphasis on ecology and innovation, but also on the development of urban agriculture.

The issue of a sustainable urbanization framework was put on the back burner by the United Nations, which proposed an international framework for urban development, focused on the 3 main pillars of sustainable development: environment, economy and social (Dima & Vasilache, 2013; Parnell, 2016). Liao and Lin (2022) propose as a model of sustainable urban development, green urban development, noting that there are two models of green urban development, the first, associated with central cities that focus on the development of human capital and the modernization of industry with minimal impact on the environment, while

non-central cities are moving towards a green economic model and the transformation of enterprises with high pollution capacity into green enterprises. An essential factor in the transition to green cities is represented by the digitization of the economic model adopted at the city level. For example, Zhu and Chen (2022) state that the digitization of the economy plays an important, faster role in the configuration of urban space than in the urbanization process.

However, the development of sustainable cities is not a uniform process. For example, Yang et al. (2017) state that there is a gap in urban development between cities in western and eastern China, as a result of sustainability measures applied by local/central government. Al-Zoabi and Jarrar (2016) state that sustainability is defined by the efficiency of this on several areas, such as: economic, energy, infrastructure, land use. Thus, in order to develop viable strategies in the area of urban sustainability, da Silva Neiva et al. (2021) propose the use of a strategic management tool, called Balanced Scorecard (BSC). The use of this tool stems from the need of urban center managers to cope with the requirements and difficulties of addressing best practices for urban development. Therefore, by using BSC, cities can become more resource efficient.

According to Fertner and Groth (2016), the process of making urban settlements more efficient should consider, first of all, the efficiency of the energy system, the use of electricity from renewable sources. On the other hand, Ciegis and Zaleviciene (2012) state that the development of sustainable cities can be achieved by harmonizing economic growth, social progress by limiting negative effects on the environment.

Even if the phenomenon of urbanization leads by itself to the reduction of green spaces, this phenomenon can be counteracted by increasing the quality of green spaces within the city, the main goal being the reduction of pollution (Haaland & Konijnendijk van den Bosch, 2015).

However, to achieve this transition towards sustainable urban development, governments must promote a legal framework and provide compensatory measures to economic actors to increase the use of circularity practices and innovation (Robinson et al., 2022). For example, despite the positive effect it generates on the reduction of carbon emissions, the digitization process of the economy is not a uniform one, with a sinusoidal evolution in spatial profile (Wang et al., 2022).

For a multi-lateral development of urban settlements, an effective tool is the use of the Data Envelopment Analysis method that allows the determination of an efficiency score at city level, called within the decision making units model. In addition, socio-economic relationships between the sampled cities can be determined based on these scores (Unsal & Nazman, 2020). Although, there is quite a bit of controversy in the field over the type of DEA model to be used (input-oriented or output-oriented), Ali et al. (2018) state that the efficiency score results are similar, but to identify the quality level of DEA results, they can be analyzed by cross-validation, using classification methods, such as: k-means clustering algorithm, support vector machines or random forest.

Through the assumed objectives, the research constitutes an element of novelty by analyzing the efficiency in the field of sustainable economic development in the urban environment, especially in the context of a sample consisting of 41 cities from countries such as: Romania, Germany, the United States of America, Australia and Japan.

Research Questions/Aims of the Research

Starting from the hypothesis of the existence of gaps in terms of urban development at a global level, the paper aims to identify urban models of efficiency from the perspective of economic growth, but also of reducing the rebound effect, generated by the economic model used. Moreover, the results of this article will identify the discrepancies in urban development at the level of the 41 statistical units analyzed in this study. So, the study aims to find out answers for two research questions.

Q1: „What are the efficient cities in terms of sustainability?”

Q2: „What are the relationships between the cities included in the sample?”

Research Methods

In order to achieve the purpose of the research, data were extracted at the level of 41 cities from 5 countries: Romania, Germany, the United States of America, Japan and Australia. As it can be seen, two countries from Europe were chosen, one country from Central America, one from Asia, respectively a country from the Oceania area. By evaluating the cities from these countries, the differences in urban development at the continent level are also evaluated. The 41 cities included in the analysis were: Bucharest, Cluj-Napoca, Timisoara, Craiova, Constanta, Iasi, Brasov, Berlin, Hamburg, Munich, Frankfurt, Stuttgart, Leipzig, Dusseldorf, Tokyo, Osaka, Nagoya, Fukuoka, Sapporo, Sendai, Okayama, Hiroshima, Kitakyushu, Naha, Kumamoto, Sydney, Melbourne, Brisbane, Perth, Adelaide, New York, Los Angeles, Chicago, Washington, San Francisco, Philadelphia, Dallas, Houston, Miami. The Decision Making Units are the 41 cities from the 5 countries. The 41 cities were selected to identify structural differences in sustainable urban development (maximizing economic growth with minimal environmental impact). Even if it could affect the precision of the estimated results, the heterogeneity of these cities represents an important aspect in outlining and identifying structural differences at the global level from the perspective of urban development. The variables were selected in compliance with Quality Assurance Framework of official statistics. Thus, the emphasis was placed on ensuring comparability between the 41 cities, the only trade-off was from the perspective of data opportunity, which was used as a result of the availability of the data. Therefore, it was selected, for each variable the last available year of the data. However, for a variable, the same reference moment was chosen at the level of all statistical units. More details about the variables can be found in Table no. 1.

Table 1. Variables description

Variable	Unit of measure	Period of reference	Source
GDP per capita	USD per capita	2020	OECD
Urban Area per capita	m^2 per capita	2014	OECD
Employment rate	%	2020	OECD
Mean population exposure to PM 2.5 air pollution	%	2020	OECD

Variable	Unit of measure	Period of reference	Source
Labour productivity	GDP per worker in USD	2020	OECD
Share of green areas in FUA's urban centres	%	2021	OECD
Working age population group (15-64)	Number of people	2021	OECD

Source: own work.

Data Envelopment Analysis (DEA) is the method used in the analysis of the economic development efficiency in the context of the sustainable development of the 41 cities included in the research. Raab and Lichty (2002) state that in order to have reliable results, the number of Decision Making Units (DMU) must be at least twice the product of the input and output variables. Another approach is formulated by Dyson et al. (2001) who state that the accuracy of the estimates requires an optimal number of Decision Making Units at least equal to 3 times number of input and output variable used. Calculating based on Raab and Lichty's formula (2022), if i is the total number of input variables (5), and o is the number of output variables (2), the minimum number of DMUs resulting would be 20, while what, based on the formula supported by Dyson et al. (2001), if m is the number of variables (7 variables), the minimum number of DMUs would be equal to 21. Therefore, as the number of Decision Making Units is 41, both criteria are satisfied. In this respect, it is not necessary to increase the discriminatory power of data from the analysis (Charles et al., 2019).

Moreover, the DEA assumptions are:

- The DMUs are not even homogeneous
- The input and outputs are not measured in the same units
- The inputs and outputs are non-negative
- The process is not characterized by a fixed set of inputs and outputs

Taking into account the DEA assumptions and the administrative differences among countries, implicitly differences in local government, a Variance Return to Scale (VRS) DEA model was used, which is suitable in such cases (Huguenin, 2012). For example, the member countries of the European Union (Romania, Germany) are governed by the *acquis communautaire*, but, at the same time, at the national level it is based on a different model of urban development. Similarly, the United States, Japan and Australia are based on their own economic, social and urban development model. DEA has to solve the following linear programming maximisation problem for each one of the j DMUs under analysis:

$$\theta = \frac{\sum_{r=1}^s \mu_{ra} * y_{ra}}{\sum_{i=1}^m \gamma_{ia} * x_{ia}} \quad (1)$$

Where:

θ = efficiency score of DMU's (0 min; 1 max)

s = no. Output variables

m = no. Input variables

y_{ra} = sum of outputs of ath DMU

x_{ia} = sum of inputs of ath DMU

considered as direct results of the actions taken at the level of the local administration (Cooper et al., 2011). In addition, in order to have reliable results, having two variables which performance is measured in the opposite direction, GDP per capita performs at the highest possible value, and PM 2.5 performs with the lowest possible value, the variable PM 2.5 has been standardized by relating the average value of the 41 cities to the individual value of each. The DEA analysis was carried out through RStudio, using deaR package.

Finally, to answer the research questions, the DEA model used is an input-oriented model, the variables that serve as input being: Urban Area per capita, Employment rate, Labour productivity, Share of green area in FUA's urban centres, Working age population group, and the two output variables in the model were: Mean population exposure to PM 2.5 ai pollution and GDP per capita.

Findings and discussions

As explained in the methodology part, a VRS model was used to determine the efficiency score, having as a result two of the variables, and the other five variables being used as input. In addition, the type of "input oriented" model was selected, as input variables can be managed directly through measures adopted at the level of local administration.

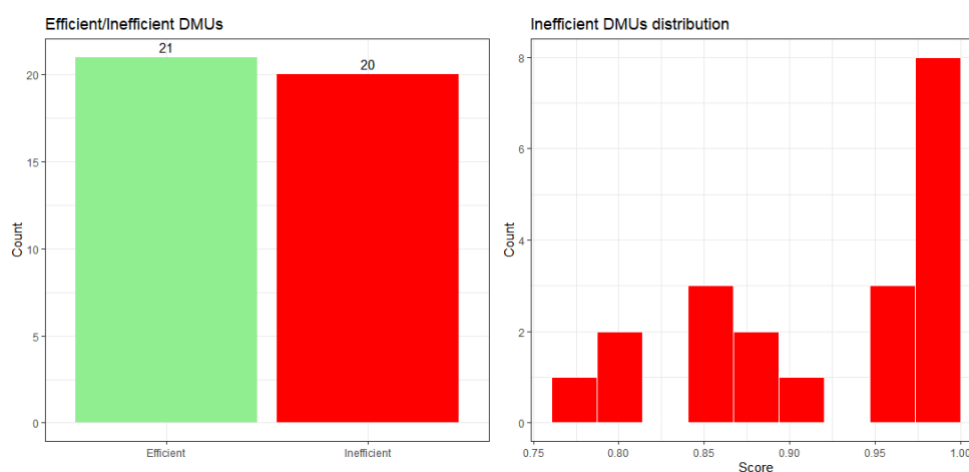


Figure 2. Efficient/Inefficient cities distribution

Source: own work, using Rstudio.

Across the 41 cities, 21 of them are efficient, while 20 are not efficient as a result of the estimated model. Interestingly, all 20 inefficient cities have a score of over 0.75, and 11 of them are in the range of 0.95-1 (Figure 2).

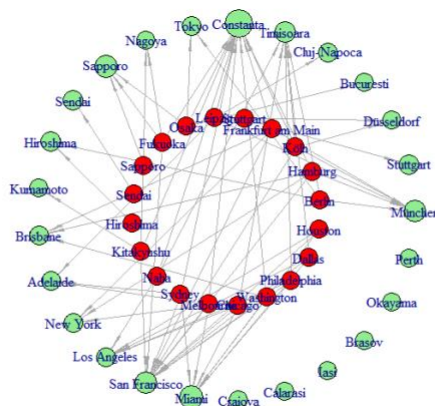


Figure 3. Diagram of cities

Source: own work, using Rstudio.

As it can be seen (Figure 3), the efficient cities, those that register a DMU efficiency score equal to 1, represented by the green color, are: Tokyo, Constanta, Timisoara, Bucharest, Dusseldorf, Stuttgart, Munich, Perth, Okayama, Brasov, Iasi, Calarasi, Craiova, Miami, San Francisco, Los Angeles, New York, Adelaide, Brisbane, Kumamoto, Hiroshima, Sendai, Sapporo and Nagoya. Interestingly, a number of six cities (Craiova, Calarasi, Iasi, Brasov, Okayama, Perth) of the efficient ones are not found in the reference set of any of the cities that register an inefficiency score. This situation leads us to the idea of an unsustainable efficiency in the future of these cities, being an atypical model of development. Among the inefficient cities are: Leipzig, Hamburg, Frankfurt, Cologne, Stuttgart, Berlin, Houston, Dallas, Philadelphia, Chicago, Washington, Melbourne, Sydney, Naha, Kitakyshu, Hiroshima, Sendai, Sapporo, Fukuoka, Osaka. Interestingly, Stuttgart, Hiroshima, Sendai, Sapporo are classified as both efficient and inefficient cities. This happens as a result of a DMU=1 efficiency score, but also the existence of a slack different from 0. Thus, these cities are technically efficient (radial), they in reality do not have an efficient development model, being classified in the category of "poorly efficient". Therefore, these 4 cities will be classified into the category of inefficient cities. A particularly important aspect is the relationship between these cities.

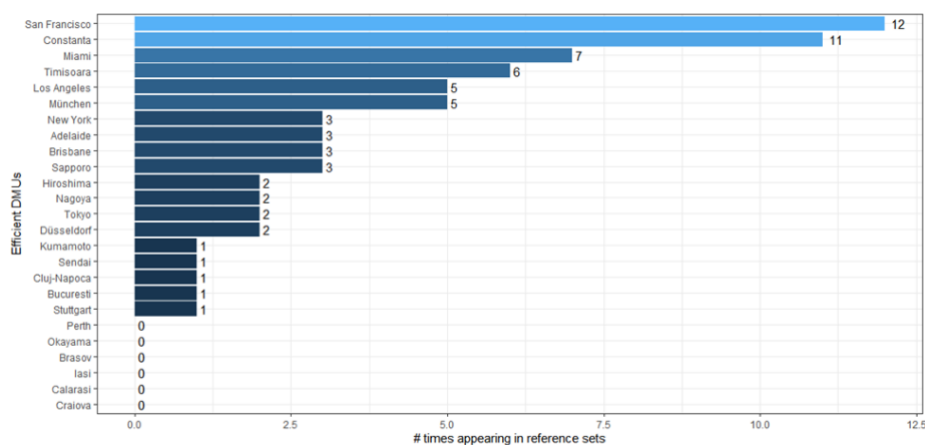


Figure 4. Times appearing in reference sets

Source: own work, using Rstudio.

San Francisco and Constanta most appear as reference cities for ineffective cities. From Romania, Constanta, Timisoara, Cluj-Napoca and Bucharest, appear at least once in the reference set of inefficient cities, while Calarasi, Craiova, Iasi and Brasov do not represent a development model for inefficient cities (Figure 4). Interestingly, the municipality of Constanta appears in the reference set of port cities, such as: Melbourne, Sydney, Osaka, Hamburg, Fukuoka or Frankfurt, which leads to the idea of an efficiency model associated with port cities.

Further, based on the reference cities that appeared in the set of each inefficient city and on the basis of slacks values, the directions for streamlining the input variables in the context of a constant output are identified.

The twenty inefficient cities are inefficient on a maximum of 3 variables in the input. In other words, all 20 cities are efficient on at least two variables in the input. For example, Sydney, Dallas, Houston, Berlin, Sapporo, Hiroshima, Melbourne, are inefficient on 3 input variables. Another series of cities, consisting of: Hamburg, Philadelphia, Cologne, Frankfurt, Stuttgart, Leipzig, Fukuoka, Sendai, Washington, Kitakyushu, Naha, Chicago are ineffective on only two variables in the input, while Osaka is ineffective on only one of the input variables. Therefore, for these cities it is very important to identify the gaps for the variables that generate inefficiency, in the context of the existing output.

In order to better understand these actions, an exemplification was made on 3 cities, each city representing a category described previously. The cities selected for example were Houston, Cologne and Osaka.

Table 3. Gaps between cities

City	Reference set	Weight
Houston	Los Angeles	0.08547
	San Francisco	0.17579
	Miami	0.73875
Osaka	Bucharest	0.08055
	Constanta	0.07485
	Tokyo	0.40178
	Sapporo	0.44283
Cologne	Munchen	0.15865
	Dusseldorf	0.09354
	Timisoara	0.21628
	Constanta	0.36801
	San Francisco	0.16351

Source: own work.

Thus, based on the data in Table 3, the target for the input variables that do not reach the efficiency value is calculated. For example, Houston is inefficient on the following variables "Labour Productivity (LP)", "Share_of_green areas", and "Urbanised_area".

$$\text{Target}LP_{Houston} = 0.08547 * LP_{Los\ Angeles} + 0.17579 * LP_{San\ Francisco} + 0.73875 * LP_{Miami} \quad (2)$$

Similarly to Eq. (2) calculate the target value for variables that record an inefficient value.

Houston Case

Houston exhibits inefficiency on 3 of the input variables, such as: "Labour Productivity", "Share of green areas" and "Urbanised area".

Table 4. Efficiency analysis of Houston

Labour Productivity			Share of green areas			Urbanised area		
Value	Target	Difference	Value	Target	Difference	Value	Target	Difference
129728	120882.4	8845.631	55.1	32.8	22.3	558	405.2	152.8

Source: own work.

There is a surplus of USD 8846 per capita for Labour Productivity which is not used to maximize output. Similarly, a 22.3% share of the city's green sufofrage share and 152.8 m² per capita of Urbanised Area do not contribute to the optimization of output.

Osaka Case

Osaka is deficient for only one of the input variables, in this case, for the variable "Labour Productivity".

Table 5. Efficiency analysis of Osaka

Labour Productivity		
Value	Target	Difference
97256	96530	726

Source: own work.

The difference between the recorded and targeted value is \$726 per capita. Thus, it can be argued that in order to option the current output of the city of Osaka, it would have taken a level of labor productivity equal to 96530 (Table 5).

Cologne Case

Cologne records inefficiency on two variables associated with input, "Labour Productivity" and "Share of green areas".

Table 6. Efficiency analysis of Koln

Labour Productivity			Share of green areas		
Value	Target	Difference	Value	Target	Difference
99199	81949	17250	50.7	34.72	15.98

Source: own work.

At the Cologne city level there is a surplus of 17250 USD per capita in terms of Labour Productivity and a surplus of about 16 percent in terms of the Share of Green Area. Therefore, it can be argued that the current level of output for the city of Cologne could have been achieved with a Labour Productivity value of 81949 USD per capita and 34.72% Share of green areas (Table 6).

The DEA results confirm the hypothesis of gaps between cities in this sample from a sustainable development perspective. Interestingly, Romanian cities are efficient from this point of view, which means that the implementation of articulated measures could lead to an even higher level of sustainability. Another interesting feature is represented by port cities

that seem to associate and follow the same pattern. Otherwise, efficient cities in one country are reference cities for inefficient cities in the same country (Munich-Stuttgart, New York-Chicago, Miami-Chicago, Tokyo-Osaka) (Figure 3).

Conclusions

The results of the research confirm the hypothesis of the study, of the existence of gaps in the efficiency of sustainable urban development. Perhaps the most important result of the research is represented by the typology of the analyzed cities in Romania. All these cities record an efficient model of the use of input variables, obtaining the maximum level associated with the output variables. Although, the relatively low level of green spaces per capita is a general feature of the cities in Romania, analyzed in this paper, it is observed that these spaces reach a high level of utility, referring to the share of the population, exposed to PM 2.5 particles. Therefore it is confirmed the idea of Haaland and van den Bosch (2015), according to which increasing the quality of green spaces can improve the relatively low level of this variable, is confirmed.

For cities that are inefficient in terms of input variables, there are a number of measures that can be adopted to make these variables more efficient. For example, depending on the typology of the city, different strategies can be adopted regarding these variables (Liao & Lin, 2022). A beneficial measure for streamlining urban agglomerations is the increase of digitalization and, implicitly, the transition to the smart-city area, an idea also supported by Zhu & Chen (2022). In addition, the transition towards a digital economy has a positive effect on the integration of circular economy concepts, which according to Robinson et al. (2022) increases the reuse rate of circulating materials.

However, as has been seen, there are certain patterns of cities, as is the case with port cities. Constanta is a reference city for all port cities (Melbourne, Sydney, Osaka, Hamburg, Fukuoka or Frankfurt) that have experienced inefficiencies in terms of input variables.

The results of this research can be used at the level of local public administration. Thus, inefficient cities can approach measures similar to the efficient cities against which they have this gap, based on the association relationship between them. In addition, cities that achieve a high level of efficiency should focus on implementing public policies aimed at further increasing the level of efficiency of input.

The discontinuity in the chronological profile of the data series was the most important limit of the research through the imperative of establishing compromises regarding the quality of the data used in this research. The chapter of conclusions should answer the research questions, discuss the issue of validity, credibility, limits of the study, generalizing the data etc. In case of hypotheses, it should present whether they were validated or not.

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