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SMART CITY EFFICIENCY ASSESSMENT MODEL: MULTI-CRITERIA ANALYSIS OF 127 CROATIAN CITIES

Abstract

Purpose: The aim of this paper is to present a model for the efficiency assessment of smart cities based on 38 indicators (ISO standard 37120, ISO standard 37122 and additional indicators) in six dimensions of a smart city in order to produce a ranking of 127 cities in Croatia.

Methodology: In this study, the Data Envelopment Analysis (DEA) method was used, which was preceded by the translator invariance method due to the standardization of 38 absolute values. The analysis was performed using the input-oriented BCC model. The input values are previously formed indices for six dimensions of smart cities; the index of the development of smart cities was selected as the output.

Results: According to the results of the ranking, 33 (26%) cities are efficient, while 94 (74%) cities are inefficient. The most efficient cities are Korčula, Split, Pazin, Rijeka and Dubrovnik, while the most inefficient cities are Skradin, Petrinja, Bakar, Komiža, Glina and Kutina.

Conclusion: By identifying the dimensions that have the greatest impact on the efficiency of smart cities, DMUs gain valuable information about the position of an individual city compared to other cities. Providing an overview of existing efficiency levels and suggesting improvement measures enables targeted changes towards efficiency.

Keywords: Smart city, relative efficiency, Data Envelopment Analysis (DEA), ISO standards

1. *Introduction*

Smart City (SC) is a term that stands for various technologies and concepts that aim to make cities more efficient, sustainable, socially inclusive and technologically advanced. The Sustainable Development Goals (SDGs) introduced by the United Nations in its 2015 Agenda for Sustainable Development (UN, 2015) and the concept of smart city (SC) are closely linked as both aim to address various global challenges and improve the quality of life of people around the world. SC initiatives contribute to SDG 11 (Sustainable Cities and Communities) by improving urban planning, expanding public transportation, promoting sustainable infrastructure and ensuring access to basic services for all residents. Smart grids, energy-efficient buildings and smart energy management systems contribute to SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action) by improving access to affordable, reliable, sustainable and modern energy, thus helping to mitigate climate change. By introducing sustainable consumption and production practices (reducing waste and promoting the circular economy), SC initiatives contribute to SDG 12 (Responsible Consumption and Production). SC initiatives also contribute to SDG 3 (Good Health and Well-Being) by ensuring healthy living and promoting well-being for all ages. By improving water management, reducing water waste and improving access to clean water and sanitation, SC initiatives contribute to SDG 6 (Clean Water and Sanitation). In summary, by integrating sustainability principles and leveraging technology, SCs can play a critical role in realizing the broader sustainable development agenda outlined in the SDGs.

Efficiency is a core principle of sustainable development and a smart use of city resources leads to greater efficiency and directly impacts the creation of greater economic value and the well-being of citizens (OECD, 2019). City efficiency primarily means targeted, coordinated, and integrated management of a smart city's infrastructure resources (e.g., energy, business, transportation, waste management, public facilities, and green spaces) using information-communication technologies (ICT) that maximize the impact and significantly reduce costs, increasing at the same time the city's sustainability. The first step is to define a vision and a strategy that reflects the characteristics of a particular city (e.g., economy, climate, natural capital, social capital, geographic location, specific industries, and infrastructure) and to implement it through all administrative structures. The second step is to integrate and coordinate policies, regulations, administrative frameworks, acts, and institutional hierarchies within which city departments operate. Formulating well-integrated management processes and activities is critical to effective urban planning and shaping a vision for the future.

In general, a greater number of quality standards met, reflecting citizens' quality of life, should improve the efficiency of the city. According to the ISO 37120 standard, the certificate is awarded to cities based on the number of indicators collected, which gives them an additional incentive, i.e. the more indicators prescribed in the standard a city meets, the higher the award. The same is true for ISO 37122, as cities that are successfully certified to ISO 37120 and are part of the World Council on City Data (WCCD) are eligible for ISO 37122 certification and able to lead the global development of smart cities with ISO-standardized, comparable city data (WCCD, 2021).

The goal of the study is to create a model for assessing the efficiency of smart cities and determine the relative efficiency of Croatian cities using DEA. This enables the identification and quantification of the efficiency factors of Croatian cities according to the Smart City Index, as all Croatian cities were included in the study. The model takes into account a large number of indicators, i.e. 38 indicators that each city must fulfil are distributed among six different smart city areas/dimensions. The inputs of the DEA analysis are the six dimensions of smart cities mentioned above, and the output is defined by the city development index.

After the introduction, this paper provides a literature review in the field of smart city efficiency assessment. After opting for the use of DEA analysis, the methodology itself is presented. It is then followed by a comprehensive description data gathering process and a variable determination process. The paper continues with a presentation of the results and finishes with a discussion and a presentation of the main findings of the paper.

2. *Literature review*

The operation of cities encompasses a rather diverse and extensive range of activities, from economic activities and governance to quality of social capital, environmental protection and sustainability, and connectivity through broadband and transportation infrastructure. Therefore, most authors group all these areas of a city into the dimensions of a smart city in order to define the most important activities and implement the strategy of a smart city. Smart cities are not a goal in themselves, but rather serve as tools to achieve a higher quality of life and sustainability goals. Achieving efficiency in various dimensions of smart cities is critical to their success.

The efficiency of smart cities can be viewed from many different angles. For example, the influence of smart city performance (SCP) on the technical efficiency and sustainability of cities was investigated by Auci and Mundula (2012) and Yigitcanlar and Kamruzzaman (2018). Auci and Mundula (2012) used a stochastic frontier analysis and found that people and environment have a positive impact on technical efficiency. Conversely, other smart indicators such as governance, economy, mobility and housing have a negative impact. Kutty et al. (2022) used the Double-Frontier Slack Based Measure DEA (DFSBM-DEA) model, which accounts for undesirable factors in long-term technological sustainability performance, to comprehend the methods cities use to tackle the problem of sustainability. The most efficient smart city was determined based on six different dimensions of sustainable development, including economic dynamics, governance and institutions, energy and environmental resources, social cohesion and solidarity, safety and security, and climate change. This approach allows policymakers to compare cities and identify areas of improvement.

The DEA allows benchmarking of smart cities based on specific dimensions such as transportation, energy consumption, waste management, and healthcare. Yu and Zhang (2019) study the influence of smart city policy (SCPol) implementation on energy efficiency (EE) in China. The findings indicate notable differences between cities in different regions, with SCPol showing a significant positive impact on EE, implying that SCPol can effectively enhance EE. Fan et al. (2021) investigated the impact of SCPol implementation on the promotion of a low-carbon economy (LCE) in China. Their findings reveal a significant improvement in the LCE of cities through the implementation of SCPol. Smart energy management strategies are critical to reducing costs and environmental footprint. In their paper, Nguyen et al. (2020) discuss the benefits of implementing the Internet of Things (IoT) in the smart city transportation system. They address the use of a hierarchical approach for overall traffic management, i.e. they define the concept, methodology, and required developments of submodels describing the optimization problems of the overall system. Transportation optimization systems are important in smart cities to alleviate traffic congestion. Yi and Ma (2019) used DEA's C2R model to evaluate the solid waste logistics system. Based on the evaluation findings, waste management and transportation were rationalized. The results indicate that the system manages logistics costs efficiently, transportation efficiency is high, the risk of waste pollution is minimized, and reliability is ensured. Smart health systems play a critical role in urban environments. Research by Pacheco Rocha et al. (2019) shows that smart cities can impact public health in a number of ways, including through disease prevention and the promotion of health initiatives. The use of smart technologies in healthcare plays an important role in patient-centred care based on patient preferences (Dukić Samaržija, Arbula Blecich & Samaržija, 2018).

Research on SC efficiency in Croatia covers various aspects related to the implementation and impact of smart city initiatives in urban areas across the country. While not measuring SC efficiency, Kelman et al. (2017) used SWAT analysis to identify the strategically important factors of a set of indicators used to govern, measure performance and improve the quality of life, using ISO 37120 Sustainable development of communities - Indicators for city services and quality of life. Jurlina Alibegović et al. (2018) assessed the largest cities in Croatia using the smart urban development index and six different dimensions (economy, people, governance, mobility, environment and living) of smart cities. According to the smart urban development index, only eleven major Croatian cities are above average, while it shows the heterogeneity of cities in all six SE dimensions. Čukušić et al. (2019) examined smart city initiatives and applications based on the simulation experiment and the opinions of 60 smart city experts. The total time of the implementation process, expressed in days, was estimated for 11 smart city applications in the city of Split. The time represents the average number of days until the start of implementation of a particular application. The results of the simulation experiment are in line with the expert assessments of the priorities and potential of smart city applications.

Buntak et al. (2021) analyzed the state of smart city development in Croatia by collecting and analyzing key dimensions of the smart city. They concluded that the implementation of smart cities is not satisfactory, which is mainly due to the lack of strategic thinking. The lack of smart city research is also evident in the systematically peer-reviewed publications dealing with research on SC in Southeast Europe (SEE). Ninčević Pašalić et al. (2021) examined, analyzed and classified seventy-four papers based on their focus on SC topics and common subtopics. While smart governance has been extensively researched in the SEE region, topics related to smart economy and smart people have received little attention from researchers. SC research in SEE is still in the conceptualization and planning stage, and there is very little evidence of the actual implementation and follow-up activities.

Overall, studies on smart cities in Croatia contribute to understanding and evaluating the efficiency of smart city initiatives in Croatia, considering citizen perspectives, financial capacities, and governance strategies. The main contribution of this paper is a holistic approach (based on 38 indicators over six SC dimensions) to efficiency assessment in order to provide a complete and credible ranking of all 127 Croatian cities, with the aim of identifying the sources of inefficiency and providing suggestions for improving the dimensions of SC.

3. Methodology

Data Envelopment Analysis (DEA) is a non-parametric mathematical method based on linear programming. It is often used to evaluate the relative efficiency of homogeneous decision-making units (DMUs) in different domains, with the main objective of optimizing resource allocation, improving performance and benchmarking. It was originally introduced by Charnes et al. (1978) and it is the estimation of the production function. The ratio of the weighted inputs to the weighted outputs is calculated for each DMU. The value q can range between 0 and 1, whereby $q = 1$ means the relative efficiency of 100%, and a value below 1 means that the DMUs operate relatively inefficiently. Relatively efficient DMUs are compared and serve as a benchmark for relatively inefficient DMUs. Relatively efficient DMUs are not able to increase any output without increasing inputs or reducing the remaining outputs, and conversely, they cannot decrease any input without simultaneously decreasing any of their outputs or increasing any of the remaining inputs.

There are two basic DEA models, the CCR model (Charnes et al., 1978), the basic DEA model, which assumes constant returns to scale (CRS), and the BCC model (Banker et al., 1984), which assumes variable returns to scale (VRS). The CRS assumes that an increase in each input for each DMU leads to a proportional increase in each output, while the VRS assumes that this relationship need not be proportional. When choosing the appropriate model, the orientation (input or output) should also be selected based on the strategy pursued by the DMUs, analysts, managers, etc. If the goal is to minimize inputs while achieving (at least) a previously reached output level, an input-oriented model is used, while an output-oriented model is chosen if the goal of DMUs is to maximize outputs with (at most) a given number of inputs. According to Mundula and Auci (2016), an efficient city has the ability to maximize its own impact (well-being) with respect to a set of inputs, i.e. to minimize the use of its own resources (inputs) to achieve a given outcome.

Since an input-oriented BCC model (VRS) is used in this paper, it can be expressed as follows (Aminuddin & Ismail, 2016):

$$
\begin{gathered}
Max\theta_0 = \textstyle\sum_{j=1}^{m} u_j y_{j0} + u_0) \\
\text{subject to} \\
\sum_{i=1}^{s} v_i x_{i0} = 1 \\
\sum_{i=1}^{m} u_j y_{jk} - \sum_{i=1}^{s} v_i x_{ik} + u_0 \leq 0 \\
v_i \geq 0, \quad u_j \geq 0, \quad u_0\ free\ in\ sign
\end{gathered}
\tag{1}
$$

Although DEA was originally developed to assess the relative efficiency of public sector DMUs, its application was later extended to the non-public sector as it can take into account multiple inputs and multiple outputs expressed in different units. DEA is often used in the area of public policy and services to evaluate the efficiency of health services (Dukić Samaržija, Arbula Blecich and Najdek, 2018; Mourad et al., 2021), educational institutions (Arbula Blecich, 2021; 2020; Arbula, 2012; Marto et al., 2022), transportation systems (Rivero Gutiérrez et al., 2022), and municipal service providers (Cerović et al., 2017). The application of DEA also extends to environmental analysis, where organizations and industries seek to assess their environmental efficiency. In this context, DEA can evaluate how efficiently resources are used to minimize environmental impacts such as pollution and waste (Elhami et al., 2016). This is especially important in today's world where sustainability and environmental responsibility are of utmost importance to investors and society. Moreover, in urban planning, DEA can help evaluate the efficiency of various urban services and infrastructure components in smart cities. DEA can evaluate how efficiently resources are used to deliver services such as transportation, energy, and waste management in terms of quality and quantity of service delivery (Nguyen et al., 2020; Yi & Ma, 2019). It can also help find ways to improve or expand urban services without significantly increasing resource consumption, contributing to the development of sustainable and efficient smart cities.

DEA is a useful analytical tool for increasing the efficiency of smart cities in a variety of areas. From assessing a city's overall performance and benchmarking specific dimensions to promoting sustainability, smart energy management, and optimizing transportation and health services, DEA plays an important role in promoting the success of smart city initiatives. Benchmarking helps cities identify best practices and areas for innovation. Researchers such as Giffinger et al. (2007) have introduced a multidimensional framework for smart cities that includes dimensions such as smart economy, smart governance, smart citizens, smart environment, smart living, and smart mobility. These dimensions are used in this paper to evaluate the efficiency of Croatian cities in their operation as smart cities and to help policy makers identify areas for improvement and allocate resources efficiently.

4. Determination of variables and data collection

The model variables were determined in several phases. In the first phase, the following dimensions of smart cities were determined: Smart Economy (SE), Smart Governance (SG), Smart Citizens (SC), Smart Living (SL), Smart Environment (SEN), and Smart Mobility (SM).

An economy is considered smart if it is able to develop innovative and modern solutions that meet the needs of the market. This means that the concept of a smart city encompasses several urban dimensions associated with SE, such as innovation, entrepreneurship and the labor market. In addition, factors such as productivity, flexibility and integration into national and international markets are also important components that need to be considered (Griffinger et al., 2007; Babić et al., 2022). Certainly, the development of a country's ICT sector plays an important role (Babić, 2021a) in achieving sustainable economic, environmental and social development.

When planning smart city solutions, particular attention is paid to the economic, social and environmental dimensions, as well as to the accountability and transparency of the governance. Extensive databases, spatial decision support systems and corresponding geodata technologies are used to facilitate city administration. In addition, smart cities are continuously innovating in the field of e-government to provide more efficient public services to their citizens (Vinod Kumar & Dahiya, 2017).

Today, city governance focuses mainly on physical features, including roads, the built environment, sewerage systems, and green spaces. Spatial planning, housing, transportation and waste management are at the forefront, while little attention is paid to e-government, i.e. the collection and processing of the vast amounts of data that can be collected as part of urban governance.

The main reason for the existence of a city and the formulation of its policies are its citizens. A crucial aspect in the development of smart cities is therefore active participation of smart citizens in urban activities in various roles (Madakam, 2014). The concept of Smart Citizens implies the educational level of the citizens of a given city and their willingness to engage in lifelong learning and progress.

Smart Living means the application of ICT with information systems for urban services in the areas of water, gas and electricity supply, telecommunications, banking, etc. in order to increase the well-being of citizens. In addition, it implies modern homes equipped with smart appliances and automation systems (Bawa et al., 2016). Although healthcare is often located outside of the city limits, the availability and accessibility of primary healthcare is an important feature of smart cities.

Smart Environment refers to the effective use of ICT to protect natural resources and cultural heritage at city level (Staffans & Horelli, 2014). It also refers to the protection of the environment and natural heritage, but especially to sustainability (Al-Nasrawi et al., 2015), as it provides advanced tools and technologies to monitor, detect, measure, and record all changes in the urban environment, as well as tools and technologies to ensure sustainability (waste management, wastewater treatment, intelligent transportation systems, etc.).

Mobility plays a crucial role in modern smart cities, as the transportation of people and goods inside and outside of the city plays a fundamental role in economic development and the improvement of everyday urban life. The difference between mobility and Smart Mobility is that in smart mobility, the public has access to real-time information and monitoring of public transportation, using ICT such as the Internet of Things, GPS, smart cameras and geographic information systems (Albino et al., 2015; Vanolo, 2014), as well as the use of environmentally friendly fuels in public transportation (Manville et al., 2014). Smart mobility is possible with an appropriate 5G network concept that combines the advantages of fixed and mobile communications (Babić et al., 2019), and this is supported by the fact that all Croatian cities are beneficiaries of the WiFi4EU initiative (European Commission, 2023), i.e. all of them have a free Wi-Fi network (Babić, 2021b).

In order to provide a holistic approach, the model consists of 38 indicators, and some of the indicators have been added so that the model can provide a more complete picture and a more credible ranking. The number of trades was included because trades play a crucial role in the economy of cities; in some cities, the number of trades exceeds the number of companies. The number of employees in the ICT sector is an indicator of the ISO 37122 standard, but it is supplemented by data on the number of ICT companies in a given city, as the application and implementation of ICT in all areas of the economy and society is the basis for creating competitiveness and ensuring the city's continued economic and social progress. In addition, the road connection to the nearest airport, the number of e-charging stations and the share of expenditure on environmental protection in the city's total expenditure, the transparency of the city's budget and the total household expenditure per inhabitant, as well as the share of citizens holding a university degree per 1,000 inhabitants, are recorded.

The data was collected from publicly available or officially requested data from public institutions. Part of the data was collected through a detailed search and analysis of the websites of all 127 Croatian cities, as well as precise measurements of the distance of all cities to the nearest airport on the Google map. The data was collected for the years 2019 and 2020 to facilitate monitoring and comparison with the same indicators in the future period, which ensures verification and comparison of the data.

Standardization was inevitable due to the range of values for the different indicators. This was done using the z-transformation method. This method involves standardization of the indicator values with the mean of 0 and standard deviation of 1 as normal distribution conditions.

$$z = \frac{-x-\mu}{\sigma} \tag{2}$$

The z-value, i.e. the standard score, quantifies the number of standard deviations by which the individual values of the observed numerical characteristic are below or above its average value. In other words, the z-value provides information about the relative position of a particular value within the overall distribution compared to the average value. Values for which a higher value is less desirable are inverted by multiplying by -1, as is the case for greenhouse gas emissions, PM10 concentration, etc.

Finally, indices are calculated and created for different smart city dimensions. Each index is assigned a z-value based on equation (2) for each indicator. Based on the z-values of the indicators, the average scores of the dimensions and consequently the average scores of each city were calculated.[1]

Each index of smart city dimensions for each individual city (DMU) represents an input for the analysis of the efficiency of the Croatian cities. The output in this model is the index of development (y1) for each city (DMU).

Table 1 Inputs and outputs

CROATIAN CITIES	**Inputs - Dimension indices**						**Output**
	Smart Economy	**Smart Governance**	**Smart Citizens**	**Smart Living**	**Smart Environment**	**Smart Mobility**	**Index of development**
DMU DOMAINS	Economy Finances	Management	Education Recreation Culture	Health Housing Safety	Energy Environment and climate Solid waste Water	Telecommunications Traffic	
DMU	SE	SM	SC	SL	SEN	SM	IoD
1 - 127	x_1	x_2	x_3	x_4	x_5	x_6	y1

Source: Authors

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[1] This work is a result of research conducted as part of the doctoral dissertation: Babić, A. (2021) Učinkovitost gradova Republike Hrvatske prema normama ISO 37120, ISO 37122 i dimenzijama pametnih gradova. Due to the extensive analysis, the reader is referred to the mentioned literature for additional explanations.

The development index was created using the balanced z-score method, a non-linear technique for creating composite indices. In this method, the values of the individual indicators are converted into standardized scores and combined into a composite index using the arithmetic mean and a penalty coefficient (Denona Bogović et al., 2017). This method is also known as the Mazziotta-Pareto index (De Muro et al., 2011). This index was developed with the aim of solving the problem of objectively measuring, evaluating, comparing and ranking units at various territorial administrative levels on the basis of their level of development in a given period. This was particularly important when individual or multiple units have mismatched sets of indicators, i.e. when they perform above average on some indicators and below average on others.

5. Results and discussion

After determining the DMUs, i.e. Croatian cities, and the input and output values, the efficiency analysis was carried out according to the BCC and CCR models. The following table presents the descriptive statistics for the inputs and outputs included in the model.

Table 2 Descriptive statistics of inputs and outputs

	X1	X2	X3	X4	X5	X6	Y
Max	0.77528	1.09076	1.06757	3.3404	83.9615	0.72155	115.637
Min	0.2556	0.33049	0.29752	0.30977	0.30613	0.25179	91.167
Average	0.51855	0.52438	0.52931	0.56863	1.17456	0.48127	103.613
SD	0.08798	0.11752	0.12872	0.32787	7.37609	0.10881	5.09866

Source: Authors

The comparison of the results of the input-oriented models CCR and BCC is summarized in Table 3 and a detailed presentation of the results of the efficiency analysis for both models for all 127 DMUs individually can be found in Babić (2021b).

Table 3 Comparison of CCR and BCC models

RESULTS OF THE ANALYSIS	CCR UU model	BCC UU model
Relatively efficient cities (number)	20 (16%)	33 (26%)
Relatively inefficient cities (number)	107 (84%)	94 (74%)
Average relative efficiency	0.8968	0.9382
Standard deviation	0.0777	0.0568
The lowest relative efficiency value	0.662	0.7708
The number (%) of cities whose relative efficiency is lower than the average	56 (44%)	60 (47%)

Source: Authors

The efficiency frontier is determined based on those DMUs that achieve the maximum efficiency (θ=1) of inputs to achieve a given level of output. Looking at relative efficiency according to the CCR model, out of the total population of all cities in the Republic of Croatia, 20 cities are relatively efficient and define the efficiency frontier. These cities are: DMU5 (Sveta Nedelja), DMU9 (Zaprešić), DMU11 (Klanjec), DMU15 (Zabok), DMU33 (Varaždin), DMU34 (Varaždinske Toplice), DMU53 (Opatija), DMU55 (Rijeka), DMU60 (Senj), DMU69 (Nova Gradiška), DMU72 (Biograd na Moru), DMU76 (Zadar), DMU100 (Sinj), DMU102 (Split), DMU111 (Buzet), DMU114 (Pazin), DMU119 (Vodnjan - Dignano), DMU120 (Dubrovnik), DMU121 (Korčula), and DMU125 (Čakovec). Since 16% of the cities are relatively efficient, their results appear as a reference set for relatively inefficient ones. These cities allow benchmarking for all inefficient cities, i.e. the reference set for inefficient cities consists of relatively efficient cities whose input-output orientation is closest to that of an inefficient city, but which are efficient based on the output achieved with the given resources.

Each inefficient city is assigned at least one reference DMU that represents best practice. According to the BCC model and taking into account the VRS, DMUs have a higher relative efficiency compared to the CCR model. The lowest value of relative efficiency is by 0.11 lower in the CCR model than in the BCC model, but the number of cities where relative efficiency is below average is higher in the BCC model (60) than in the CCR model (56). For further analysis, the input-oriented BCC model is used because it is translationally invariant with respect to both inputs and outputs, in contrast to the CCR model, which is not translationally invariant because of the shape of the envelope it forms (Knox Lovell & Pastor, 1995). This is important for the analysis presented in this paper.

The reference set allows relatively inefficient DMUs to pursue achievable goals. Since the projection of inefficient cities to the efficiency frontier is expressed by a linear combination of efficient cities from the reference set whose coefficients represent their share of a single city's projection to the efficiency frontier, the city with the highest corresponding coefficient should be chosen as the reference. The reference set for inefficient cities is shown in the following table.

Table 4 Reference set for inefficient cities

DMU	Reference city	Number of cities	%	Reference set of inefficient cities
DMU120	Dubrovnik	28	30%	Cres, Crikvenica, Garešnica, Glina, Ivanić-Grad, Kraljevica, Križevci, Krk, Kutina, Ludbreg, Makarska, Mali Lošinj, Novi Vinodolski, Omiš, Poreč, Rab, Rovinj, Samobor, Šibenik, Komiža, Sisak, Slavonski Brod, Solin, Trogir, Umag, Velika Gorica, Vis, Vrbovec
DMU114	Pazin	15	16%	Belišće, Daruvar, Županja, Ivanec, Hvar, Krapina, Lepoglava, Opuzen, Slatina, Orahovica, Supetar, Virovitica, Vrgorac, Novigrad, Hrvatska Kostajnica
DMU34	Varaždinske Toplice	10	11%	Knin, Trilj, Mursko Središće, Oroslavje, Ozalj, Petrinja, Popovača, Pleternica, Sveti Ivan Zelina, Zlatar
DMU14	Pregrada	6	6%	Beli Manastir, Benkovac, Donja Stubica, Duga Resa, Ilok, Otok
DMU95	Imotski	5	5%	Buje, Donji Miholjac, Kutjevo, Novi Marof, Vukovar
DMU11	Korčula	5	5%	Prelog, Ploče, Pag, Novalja, Grubišno Polje
DMU121	Klanjec	4	4%	Obrovac, Skradin, Pakrac, Slunj
DMU15	Zabok	4	4%	Nin, Požega, Lipik, Gospić
DMU111	Buzet	4	4%	Vrlika, Stari Grad, Delnice, Bakar
DMU80	Đakovo	3	3%	Metković, Drniš, Valpovo
DMU125	Čakovec	3	3%	Vodice, Novska, Jastrebarsko
DMU69	Nova Gradiška	2	2%	Vinkovci, Našice
DMU102	Split	1	1%	Kaštela
DMU76	Zadar	1	1%	Bjelovar

DMU	Reference city	Number of cities	%	Reference set of inefficient cities
DMU56	Vrbovsko	1	1%	Čabar
DMU55	Rijeka	1	1%	Karlovac
DMU5	Sveta Nedelja	1	1%	Kastav
TOTAL		94	100%	

Source: Authors

The cities most frequently mentioned in the reference sets of inefficient cities are DMU120 (Dubrovnik), DMU114 (Pazin) and DMU34 Varaždinske Toplice. By comparing empirical and projected values for all 127 cities, the sources of inefficiency and their magnitude were identified for six inputs and one output. A larger percentage difference between the projected and empirical values of a particular input or output means that the input or output is a greater source of inefficiency. The following table shows, for all inputs and outputs, the changes that inefficient cities must make to achieve relative efficiency. These are average percentage changes per inefficient city and changes for individual cities that require the greatest improvement in individual inputs or outputs.

Table 5 Results on average improvements for relatively inefficient inputs

Inputs/Outputs	Empirical value	Projected value	Difference (%)
(x1) Smart Economy	0.5185	0.4789	7.0622
(x2) Smart Governance	0.5244	0.4674	9.8196
(x3) Smart Citizens	0.5293	0.4618	10.8195
(x4) Smart Living	0.5686	0.5053	9.5471
(x5) Smart Environment	1.1746	0.4761	7.9944
(x6) Smart Mobility	0.4813	0.4219	11.2067
(y1) Index of development	103.613	106.756	3.1506

Source: Authors

Since all input values are inverted, all output values are increased, even though the interpretation of the results speaks of a decrease in input. The projection shows that input x1 (SE) can achieve the same output level with 7.06% less input, input x2 (SG) with 9.82% less input, input x3 (SC) with 10.82% less input, input x4 (SL) with 9.55% less input, input x5 (SEN) with 8% less input, and for input x6 (SM) with 11.21% less input with the same output level, which represents increases in the non-inverted values. This shows that inputs x3 and x6 have the greatest impact on city inefficiency, followed by x2, x4, and x5, while input x1 has the least impact on city inefficiency.

6. Discussion and conclusion

Smart cities use data and technology to operate efficiently, promote economic development, improve sustainability and enhance the quality of life of people living and working in the city. The indicators of ISO standard 37120 - *Sustainable cities and communities*, and ISO standard 37122 - *Indicators for smart cities and additional indicators applicable to all cities* were used as a basis for creating a model for assessing the efficiency of Croatian smart cities within the framework of smart urban units, regardless of their size. The main contribution of this paper is that for the first time, all Croatian cities have been ranked using comparable and verifiable data based on a comprehensive database (38 indicators), which provides a model for assessing the efficiency of Croatian smart cities.

DEA was used for the efficiency analysis. The input values were represented by previously formed indices for six dimensions of smart cities, and the output was the development index, which is a reliable official statistic and one of the most important instruments of regional policy. The ranking resulted in efficient cities that are at the efficiency frontier and whose reference value is equal to one, while inefficient cities have values below one. The analysis was carried out using the input-oriented BCC model. This analysis identified efficient cities, inefficient cities and a reference group consisting of efficient cities that are most similar to the inefficient cities. For cities identified as relatively inefficient, the causes of relative inefficiency were identified in order to make recommendations and predictions on how much at least one dimension needs to be improved in order to reach the efficiency frontier based on their reference group. By identifying the dimensions that have the greatest impact on the efficiency of smart cities, cities gain valuable information about their individual position compared to other cities. Providing an overview of existing efficiency levels and suggesting improvement measures enables targeted changes toward efficiency.

However, the study has certain limitations, which mainly relate to the data set from 2019 and 2020. This is due to the fact that the paper is based on a comprehensive doctoral dissertation investigation, which includes both publicly available data and data officially requested from public institutions, as well as a detailed search and analysis of the websites of all 127 Croatian cities and accurate measurements of the distance of all cities to the nearest airport on Google Maps. Furthermore, the output variable in this model is the index of development of Croatian cities, for which no new data has been published yet. For further research, it is advisable to conduct a detailed analysis of the individual SC dimensions and introduce the second stage statistical analysis to determine the influence of exogenous factors. Since no data over a longer period of time was available, a DEA analysis based on one year was performed, while for further research it would be advisable to perform a dynamic DEA analysis. Finally, the model also has additional potential by extending the analysis of the existing model to new regional entities (municipalities) and applying new methods and measurement approaches. This comes with limitations, mainly because many initiatives in Croatian cities are still in their infancy and there are still many obstacles to overcome, especially when it comes to collecting data for the purpose of additional analysis in cities.

Regarding Smart Mobility in the context of telecommunications and transportation in particular, it is clear that not all cities have the same speed or access to the internet and that not all cities have a developed transportation system equipped with digital parking solutions, payment technologies, online parking or the presence of electric charging stations. Without these smart technologies, inefficient cities use telecommunication and transportation resources in a sub-optimal way, which is also reflected in their level of development.

The Smart Citizen dimension is the second largest source of inefficiency in inefficient cities. It relates to education, sport and culture, and it is one of the most important dimensions when it comes to a city's social capital. The implementation of more effective and targeted population policies as well as the co-financing of student activities and scholarships, investment in sports infrastructure and sporting events are just some of the measures that could improve the use of resources in this dimension.

The impact of the Smart Living dimension relates to the quality of life in terms of smart technologies (smart electricity), security (live cameras) and primary healthcare (the ratio of primary healthcare physicians to inhabitants). These are indicators that need to be improved and are not always the responsibility of the city administration. The specific increase in the share of smart electricity is the responsibility of Hrvatska elektroprivreda (HEP d.d.), and there are numerous ongoing projects related to the implementation of smart living solutions that have a direct impact on the better quality of life of citizens.

This study also suggests that Smart Governance is a very important dimension that needs to be improved, as current governance models should utilize the city's resources (businesses, people and technology) more efficiently. Smart Environment and Smart Economy are two dimensions that have proven to be less problematic, but still require better resource utilization, such as better waste management and water supply systems, as well as better road connections and investment in research and development.

To summarize, this paper provides a comprehensive assessment of Croatian (smart) cities and identifies the main sources of inefficiency. This should help policy makers and urban planners to focus on the areas where improvements are needed in order to promote overall urban development and smart city initiatives.

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