УДК 338.28:004.67:001.895
https://doi.org/10.30838/EP.200.232-242

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THE SOCIO-ECONOMIC PARADIGM OF «SMART INFRASTRUCTURE»: THE CASE OF UKRAINE

Analytical data are presented on transformational indicators in Ukrainian cities, alongside a comparative cartographic analysis of countries leading in smart city development. This includes correlations with the Human Development Index, Gender Inequality Index, Gender Development Index, and the E-Government Development Index.

The article examines potential pathways for building smart infrastructure in Ukrainian cities, emphasizing the importance of partnerships with leading European nations known for their high levels of digitalization and competitiveness. An assessment of the Regional Digital Transformation Index and digitalization levels across Ukraine is also provided.

Based on the conducted research, the authors propose a theoretical model for the strategic development of smart infrastructure in sustainable urban communities. This model emphasizes a human-centered approach. The study concludes that the concept of smart cities is gaining increasing relevance in Ukraine and requires in-depth exploration not only for large cities but also for smaller urban settlements. The developed approaches, theoretical frameworks, and identified issues may serve as a foundation for future public policy planning in the context of post-war recovery and the socio-economic paradigm of smart city functionality. The formation of smart cities is a global trend, which emphasizes the relevance of the research and requires solving many current problems regarding the implementation of smart technologies, which are critically important for the management system functioning of the at the city level.

Keywords: *smart infrastructure, smart cities, urbanization, digitalization, transformation, models, scenarios, concepts.*

JEL Classification: *R 58, A13, H54*

СОЦІАЛЬНО-ЕКОНОМІЧНА ПАРАДИГМА «SMART-ІНФРАСТРУКТУРИ»: КЕЙС УКРАЇНИ

У статті проведено теоретико-методологічне обґрунтування сучасних тенденцій, положень, інструментів та розробки орієнтирів розбудови в контексті соціально-економічної парадигми «smart-інфраструктури» сталого міста в Україні за відсутності єдиної універсальної моделі «розумного» міста; проведний огляд літературних джерел щодо наукового підґрунтя та трактування терміну «розумне» місто, переваги, виклики та проблеми впровадження «розумної» інфраструктури, виокремлені концепції та типологія сучасних смарт-міст; представлена аналітична інформація показників трансформаційних змін в українських містах та порівняльний аналіз картограми країн світу з провідними смарт-містами та функціонуючим Індексом людського розвитку, Індексом гендерної нерівності, Індексом гендерного розвитку, Індексу розвитку електронного уряду; розглянуто можливі шляхи побудови «розумної інфраструктури» пов'язані зі сталим містом в Україні, а саме: розширення співпраці з провідними країнами Європи, що володіють високими характеристиками цифровізації та конкурентоспроможності, проведенна оцінка Індексу цифрової трансформації регіонів і рівень їх цифровізації; на основі проведеного дослідження авторами надано теоретичну модель стратегічного розвитку «smart-інфраструктури» сталого міста в громадах, яка фокусується на людино орієнтованому підході.

Зроблено висновок, що концепція «розумного» міста в Україні стає все більш актуальною, потребує детального дослідження, і не лише великих, а й невеликих міст, розроблені підходи, теоретичні положення і нагальні питання, які можуть бути використанні для подальшого планування державної політики у сфері громадського управління в контексті післявоєнної відбудови та соціально-економічної парадигми функціонування «smart-інфраструктури» сталого міста в Україні. Формування розумних міст є глобальним трендом, що свідчить про актуальність дослідження та потребує розв'язання багатьох актуальних проблем щодо впровадження смарт-технологій, які є критично важливими для функціонування системи управління на рівні міста.

Ключові слова: *«smart-інфраструктура», «розумні» міста, урбанізація, цифровізація, трансформація, моделі, сценарії, концепції.*

Problem statement. The concept of the smart city is gaining increasing importance, particularly for Ukraine - a country currently in a state of war, undergoing socio-economic transformation, and seeking pathways to recovery. The integration of smart technologies into urban governance has the potential to address a range of pressing issues, including effective resource management, public safety, environmental sustainability, and the development of innovative solutions. Additionally, the training of professionals capable of working with advanced technologies is critical and constitutes an essential component of the country's reconstruction process.

One of the central challenges of post-war recovery in Ukraine is the restoration of urban infrastructure and the modernization of municipal governance systems. The smart city concept, already being implemented in over 2,500 cities around the world, offers substantial opportunities to accelerate these processes. Numerous academic studies have emphasized the urgent need to promote the development of Ukrainian smart cities within regional and territorial communities. Key priorities include automating routine administrative functions, increasing the efficiency of local governance, reducing public expenditure, and promoting the rational use of natural resources.

The formation of smart cities has become a global trend that spans a wide array of countries and regions. From a theoretical standpoint, the relevance of this study lies in the fact that no single, universally accepted model of a smart city currently exists. Much depends on the collaboration and initiative of key stakeholders, including businesses, governments, civil society, and residents themselves. The successful implementation of smart city technologies requires a reliable and cost-effective internet infrastructure, a well-developed ecosystem of internet-connected devices, and the capacity to process large volumes of data. This, in turn, implies the need to integrate various urban information streams into a unified operational center, which would serve as a central command hub - overcoming administrative fragmentation and coordinating the spatial distribution of key infrastructure elements.

Analysis of the latest research and publications. Scholars describe the concept of the «smart city» as an attempt to address a fundamental challenge: reducing costs while simultaneously increasing revenue, maintaining stability, enhancing the responsiveness of public services, and improving the quality of life for citizens. The smart city paradigm is also associated with an alternative perspective that emphasizes citizen-centric urban governance. However, this governance model may lack the advantages of a purely economic perspective and is often characterized by the absence of appropriate legal frameworks capable of addressing and meeting social challenges (Kitchin, 2022).

What was once considered a futuristic vision of a civilized urban environment has become increasingly realizable through the integration of digital technologies. Smart cities interconnect people, information, technologies, and processes within a complex global infrastructure. This infrastructure is utilized to enhance both economic and

political efficiency, while simultaneously supporting social, cultural, and urban development (Burch, 2019).

Despite its promising nature, the concept of a smart city lacks a universally accepted set of attributes or requirements. There remains ambiguity about what exactly constitutes a smart city and what its residents should expect. Scholars conceptualize it as encompassing technological scope, the human dimension, and institutional frameworks (Cocchia, 2014); as a combination of technology, future well-being, system integration, and process orientation (Javidroozi et al., 2014); or as a technical infrastructure classified into four dimensions: technical components, application domains, systems integration, and data processing (Yin et al., 2015).

A smart city, therefore, is defined by the use of software, hardware, and network technologies in coordination with local authorities, education, healthcare systems, and other institutions (Nam & Pardo, 2011). Experts recognize the value of sensors, networks, computers, and other technological innovations in designing, building, and maintaining urban infrastructure aimed at creating safe, sustainable, and efficient cities (Hall et al., 2000). Other analysts view the smart city as an integrated network of services and technologies, enabling data analysis, optimization, and visualization (Harrison et al., 2010).

The research focusing on the development of smart infrastructure for sustainable cities reveals certain gaps and challenges in the mechanisms underlying smart city systems. These issues are explored in both national and international scholarly work. While the modern management styles of sustainable urban development have been widely addressed, overall smart development - both globally and particularly in Ukraine - still faces critical conceptual and practical barriers.

Purpose of the article. The primary objective of this study is to provide a theoretical foundation for current trends, methodological approaches, tools, and the development of strategic guidelines within the socio-economic paradigm of smart infrastructure for sustainable urban development in Ukraine - particularly in the context of the absence of a unified, universal model of a «smart city».

Main results of the study. Today, the city represents the most prominent form of territorial and economic organization in modern society. With each passing year, it becomes increasingly evident that cities around the world are expanding beyond their traditional boundaries and, more than ever, are acquiring greater authority and visibility in globalized domains such as climate change mitigation, migration governance, and the advancement of digital technologies.

Urbanization has been accelerating , being driven by both natural population growth and migration. Therefore, cities, both large and small, are destined to remain critical drivers of economic development, political evolution, and social progress, exerting an undeniable influence on national prosperity. In some countries, such as South Korea, the capital city accounts for approximately half of the national GDP. Cities like Amsterdam, Barcelona, Berlin, London, Madrid, and Singapore have become successful global centers of economic activity and are increasingly integrated into the global network of innovation and influence. The global GDP is projected to grow from $87.8 trillion (2019) to $115 trillion by 2030 (UN World Urbanization Prospects, 2018).

There is no universally accepted international definition of a «smart city». In academic discourse, a range of terms is used, including the following: «intelligent city» – referring to a city's capacity to generate and distribute unique intellectual capital; «digital city» – focused on data processing and information dissemination; «sustainable city» – oriented toward the adoption of energy-efficient practices and green technologies; «technosite» – emphasizing the quality of logistical and transport infrastructure; «welfare city» – enhancing territorial attractiveness through climatic, cultural, and technological advantages; «sustainable smart city» – an innovative urban space that leverages ICT and other methods to improve quality of life, optimize municipal operations, and ensure sustainable development for future generations.

The implementation of the smart city concept remains a strategic priority in urban development agendas across advanced countries in Europe, Asia, and North America. Each nation adapts the smart city model to address its unique challenges. Typically, smart city initiatives employ digital technologies to improve the efficiency of municipal services and compete for resources in an increasingly interconnected global environment.

Despite its advantages, the rollout of smart infrastructure faces several key challenges, including the high cost of advanced technologies, the need for modernization of existing urban systems, and data protection and privacy concerns. Cities must strike a balance between introducing innovation and safeguarding the personal information collected in real time through numerous sensors and data systems. Additionally, it is crucial to enhance digital literacy among citizens so that they can effectively engage with and benefit from the opportunities offered by smart infrastructure.

According to the Regional Digital Transformation Index, introduced by the Ministry of Digital Transformation of Ukraine, it enables the assessment of the effectiveness of digital solutions in real-world scenarios and provides insights into the level of digital culture among citizens. The Index summarizes the annual performance of regional CDTO teams and digital teams within Oblast Military Administrations (OVAs) based on newly introduced indicators, including healthcare protection, civil security, and the accessibility of administrative services. In this sense, the Index serves as a key tool for evaluating the extent of digital transformation across the country.

The proposed methodology is based on a combined approach, which measures both digital services and infrastructure, as well as the digitalization progress within OVAs and other local communities. The highest possible score is 1.00, representing the maximum capacity in five core dimensions such as digital economy indicators, digital skills, infrastructure development, public services and the transformation of local government institutions into digital formats (Table 1).

Table 1

Regional Digital Transformation Index of Ukraine: Total Results 2023

Name of Region	Digital Transformation Index Value
Overall for Ukraine	0,632
Dnipropetrovsk	0,908
Lviv	0,891
Poltava	0,833
Volyn	0,831
Ternopil	0,827
Kharkiv**	0,787
Odesa	0,785
Vinnytsia	0,777
Zakarpattia	0,732
Rivne	0,727
Ivano-Frankivsk	0,685
Kyiv	0,684
Cherkasy	0,672
Khmelnytskyi	0,620
Zhytomyr	0,560
Chernihiv	0,553
Chernivtsi	0,546
Kirovohrad	0,531
Mykolaiv**	0,441
Luhansk*	0,404
Donetsk**	0,359
Kherson**	0,316
Zaporizhzhia**	0,289
Sumy	0,178
Autonomous Republic of Crimea***	0,000

** Index value for Luhansk region is as of February 24, 2022*

*** In regions where active hostilities are ongoing, the index is calculated for communities controlled by the Ukrainian Government*

**** The Autonomous Republic of Crimea is Ukraine*

Source: compiled by the authors based on «Digital Transformation Index of Ukrainian Regions: 2023 Results», Ministry of Digital Transformation of Ukraine, 2023.

According to the Digital Transformation Index of Ukrainian Regions, the average score across Ukraine in 2023 was 0.632. The highest-performing regions included Dnipropetrovsk (0.908), Lviv (0.891), and Poltava (0.833). The Index itself is composed of eight key components: institutional capacity, internet penetration, development of administrative service centers (CNAPs), and the implementation of Industry 4.0 transformation (Ministry of Digital Transformation of Ukraine, 2023).

Among these categories, the highest scores were recorded for the implementation of paperless governance (0.697), institutional capacity represented by the presence of Chief Digital Transformation Officers (CDTOs) and digital teams in regional military administrations (OVAs) (0.678), and the realization of basic digital services (0.666).

Efforts by CDTOs to implement digital transformation in the regions significantly accelerate the reform process; however, additional staffing is required in regions such as Kharkiv (57.1%), Kyiv (46.0%), and Mykolaiv (44.4%) to support further digitalization efforts.

Over the past four years, CDTO teams have initiated more than 210 unique interdisciplinary projects, advancing digital initiatives across Ukraine. The Index also made it possible to assess the availability of internet access in shelters of public institutions. According to the findings, 71% of secondary schools, 67% of preschools, and 57% of healthcare facilities have internet access in shelters. The «Digital Education» component of the Index also showed improvement - rising to 0.656 in 2023 from 0.460 in the previous year (Digital Transformation Index of Ukrainian Regions 2, 2023).

Thus, the Digital Transformation Index of Ukrainian Regions serves as a vital tool for assessing the readiness of cities to implement smart infrastructure. It supports effective planning of digitalization processes in urban governance, thereby ensuring sustainable development and enhancing the quality of life for citizens. Regions that achieve high levels of digital transformation are better positioned to implement innovative solutions that contribute to economic, environmental, and social resilience (Kulishov et al., 2024).

In the global study of smart city indexes and key development factors, special attention is given to the analysis of the Human Development Index (HDI), as its core dimensions - a long and healthy life, access to knowledge, and a decent standard of living - are foundational to the

formation of smart infrastructure. In the following section, we analyze the HDI of countries where the world's leading smart cities are located, and identify these cities along with their national contexts. We will also calculate the average HDI values across five selected country groups and present a comparative analysis with Ukraine's Human Development Index. Fig. 1

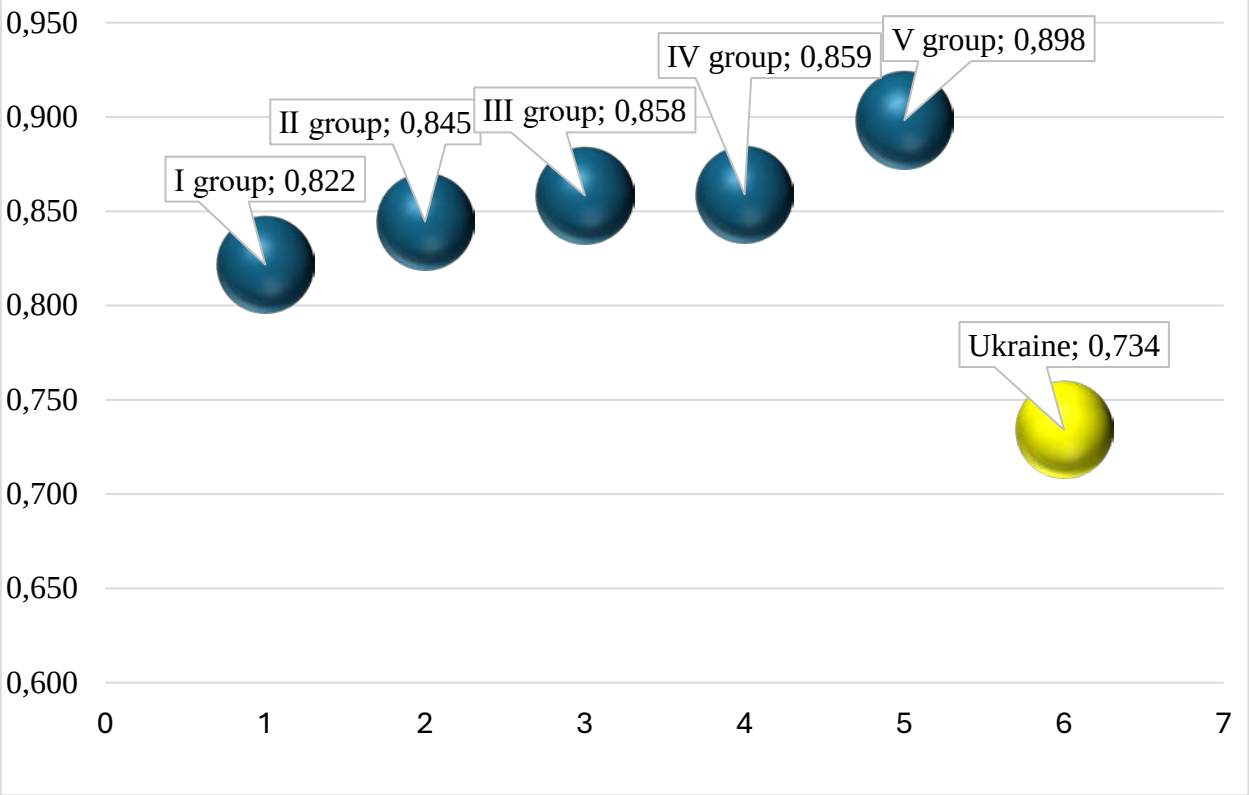

Figure 1. Cartographic Grouping of Countries by Number of Smart Cities with Average Human Development Index (HDI) Values per Group and Ukraine's HDI

Source: compiled based on data from Smart City Observatory. IMD – International Institute for Management Development, 2024. https://www.imd.org/smart-city-observatory/home/methodology/; (https://www.imd.org/smart-city-observatory/home/methodology/) Human Development Report 2023–24. United Nations Development Programme, 2024.

A key factor in the development of smart cities is the level of human development in society. Ukraine's Human Development Index (HDI) currently stands at 0.734, classifying the country as having a high level of human development and placing it 100th among 193 countries and territories. However, Ukraine is experiencing the negative consequences of a declining HDI, which has fallen to its lowest level since 2004.

In addition to the HDI - which is a composite index measuring average achievements in three basic dimensions of human development: a long and healthy life, access to knowledge, and a decent standard of living - other important indicators include the Gender Inequality Index (GII) and the Gender Development Index (GDI).

According to the GII, Ukraine scored 0.188, ranking 48th out of 166 countries, based on three core dimensions: reproductive health, empowerment, and labor market participation. In Ukraine, the HDI for women is 0.741, compared to 0.726 for men. As a result, the Gender Development Index (GDI) - calculated as the ratio of female to male HDI - is 1.021, reflecting progress in gender equality across the core human development dimensions: health, education, and income. Ukraine's GDP per capita has declined by approximately 32.1% between 1990 and 2022. When adjusted for socio-economic inequality, Ukraine's HDI falls to 0.676, representing a «development loss» of 7.9% due to inequality. As inequality increases, the losses in human development become more pronounced (Smart City Observatory. Report 2023–24).

Emerging digital technologies - including artificial intelligence, robotics, and information and communication technologies - are transforming how people live, work, and learn. Governmental regulation and leadership are expected to play a central role in shaping new models of smart urban governance to foster innovative societal development.

An important indicator of a government's readiness to transition toward smart urban, community, and national governance is the E-Government Development Index (EGDI), which reflects the status of e-government development across UN member states. In addition to evaluating the maturity of national web services, the EGDI also considers access-related dimensions, such as infrastructure and educational levels, to assess how effectively a country leverages information technologies to promote accessibility and citizen engagement. The EGDI is a composite index based on three essential components: online service delivery, telecommunication infrastructure, and human capital.

In 2024, the global average EGDI score rose from 61.02% (2022) to 63.82%. Notably, 71.5% of UN member states recorded a high or very high EGDI level, compared to 68.91% in 2022. Most significantly, the share of the global population lagging in digital government development decreased from 45% in 2022 to 22.4%, primarily due to strong progress in Asia (where the average EGDI rose by more than 12% since 2018), followed by Africa (8.26%) and Latin America (6.78%) (Fig. 2) (E-Government Development Index (EGDI), 2024. United Nations. (Retrieved from: https://publicadministration.un.org/egovkb/en-us/About/Overview/-E-Government-Development-Index).

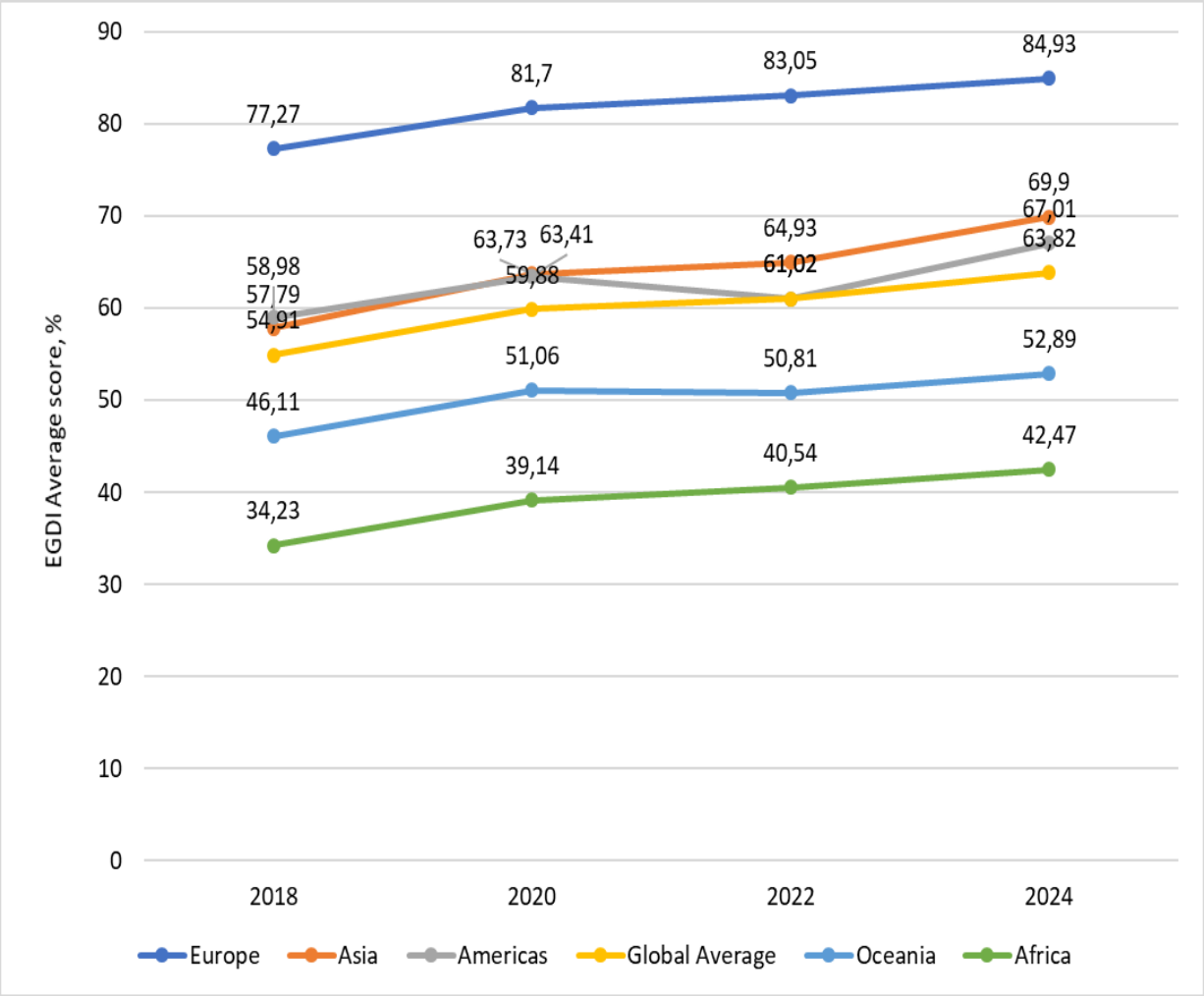

Figure 2. Dynamics of the E-Government Development Index by World Regions, 2018–2024 (%)
Source: compiled based on data from E-Government Development Index (EGDI), 2024. United Nations. Retrieved from https://publicadministration.un.org/egovkb/en-us/About/Overview/-E-Government-Development-Index. (https://publicadministration.un.org/egovkb/en-us/About/Overview/-E-Government-Development-Index)

Europe and Asia report the highest proportions of countries with very high EGDI rankings - 84% and 43%, respectively. For comparison, only 31% of countries in the Americas, 14% in Oceania (specifically Australia and New Zealand), and 2% in Africa (Mauritius and South Africa) have achieved similarly high standings.

At the national level, Denmark, Estonia, and Singapore received the highest EGDI scores in 2024. Bahrain, Germany, Ireland, and Saudi Arabia also ranked within the global top 20, benefiting from the relative decline in the positions of Austria, France, Israel, and Malta (Fig. 3).

According to the 2024 E-Government Development Index, Ukraine has significantly improved its performance in the field of digital public services, rising from 102nd place in 2018 to 5th place in the Online Services Index. This index evaluates the quality, accessibility, and usability of government e-services and websites.

Ukraine became the first country in the world to introduce digital passports, and one of the first in Europe to launch officially recognized COVID-19 certificates. The Diia (Дія) mobile application—currently used by approximately 21 million citizens - provides access to 21 digital documents and over 30 public services.

Despite the ongoing full-scale war, Ukraine continues to expand its digital infrastructure, launching new services such as eDocument, eSupport, and eRecovery to ensure that citizens can access essential public services online (MinDigit: 2 Years in Action, 2024. Ministry of Digital Transformation of Ukraine). The authors have also calculated a retrospective dynamic of Ukraine's E-Government Development Index from 2003 to 2024 (see Fig. 4).

Figure 3. E-Government Development Index Scores of European Countries in 2024

Source: compiled based on data from E-Government Development Index (EGDI), 2024. United Nations. Retrieved from: https://publicadministration.un.org/egovkb/en-us/About/Overview/-E-Government-Development-Index

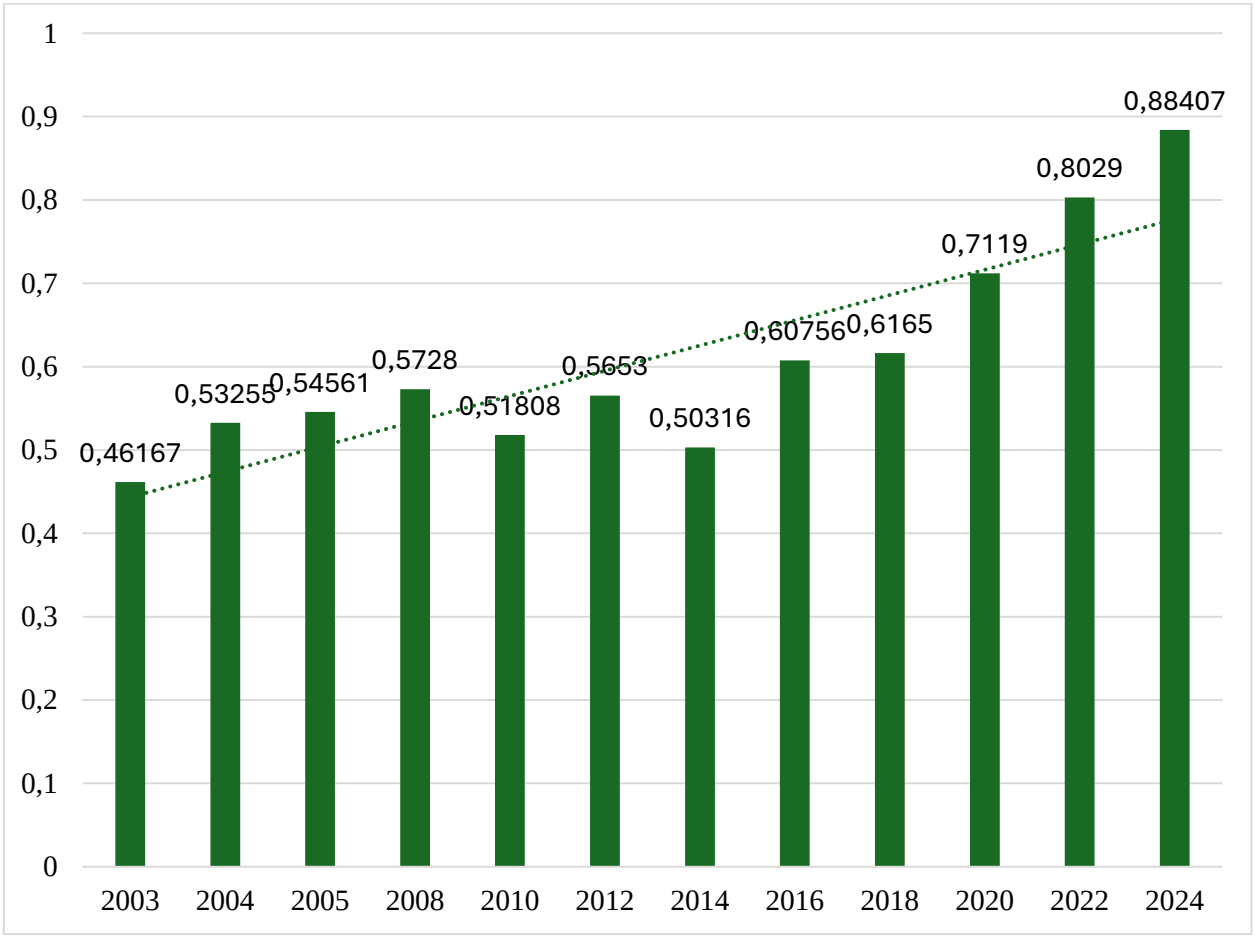

Figure 4. Dynamics of Ukraine's E-Government Development Index, 2003–2024 (%)

Source: compiled based on data from E-Government Development Index (EGDI), 2024. United Nations. Retrieved from: https://publicadministration.un.org/egovkb/en-us/About/Overview/-E-Government-Development-Index. (https://publicadministration.un.org/egovkb/en-us/About/Overview/-E-Government-Development-Index)

The analysis shows that Ukraine has been maximizing its digital potential and accelerating the development of e-governance since 2018. The country's rapid digital advancement is driven by a combination of cutting-edge technologies, strategic investments, and strong political will. Digital government initiatives have proven to be powerful tools for accelerating and realizing the Sustainable Development Goals (SDGs), serving as an indicator of a government's overall capacity to respond to contemporary challenges, including transparency, efficiency, inclusivity, and resilience (The Sustainable Development Goals (SDGs), 2024. United Nations Development Programme. Retrieved from https://www.undp.org/ukraine/sustainable-development-goals). (Retrieved from: https://www.un.org/sustainabledevelopment).

The effective digital transformation of Ukraine's regions requires a comprehensive and systemic approach. Key steps include expanding institutional capabilities, building internet infrastructure, and modernizing the State Register of Citizens. These efforts are essential for long-term development and improving the quality of life. Rapid national digital transformation demands the coordinated efforts of local authorities, civil society, and the private sector to achieve sustainable results and ensure the competitiveness of each region within the broader context of digital progress.

Among the potential development scenarios for smart infrastructure in Ukraine's sustainable urban framework, the following strategies can be identified (Current World Population, http://www.worldometers.info/world-population):

- firstly, expansion of cooperation with European countries that already possess successful digitalization experience. Each region should analyze the transformation pathways of others to define its own tailored strategy. This interaction should result in joint initiatives, projects, and policies. Continued dialogue demonstrates the government's commitment to long-term progress and innovation;
- secondly, annual assessment of the Digital Transformation Index at the regional level enables recognition of both strengths and weaknesses in the digitalization process. This transparency helps communities understand where to focus their efforts and resources while fostering their capacity to autonomously manage digital transformation;
- thirdly, enhancement of regional competitiveness: Regions that successfully adopt digital technologies are more likely to attract investment and promote business development. This, in turn, contributes to broader economic growth and reduces regional disparities;
- finally, post-war recovery through digital tools: a high level of digital transformation can mitigate the long-term socio-economic consequences of war. The

availability of fast and high-quality digital public services can soften the impact of crisis on citizens' lives and help accelerate recovery.

In view of the potential advantages of smart infrastructure in sustainable Ukrainian cities, it is critical to identify the future drivers of transformation—specifically, real economic sectors and types of economic activity that can generate high value-added products and services based on innovation, and that can be competitive in international markets. Considering the strong correlation between urban smartification and the Human Development Index, the authors propose a strategic shift in public policy toward a human-centered model of urban and community development. Prioritizing human capital enhances citizens' well-being and innovation potential, forming a foundation for the successful implementation of smart infrastructure in Ukrainian municipalities. Furthermore, as the conducted research has shown, during the post-war recovery period, the most appropriate approach involves the implementation of «experimental smart bridges» - pilot projects that emphasize a human-centered model of development. Accordingly, a foundational model for the strategic development of smart infrastructure in sustainable urban communities across Ukraine has been proposed (Bobukh et al., 20XX).

In recent years, Smart City concepts have gained popularity in leading Ukrainian cities, and several modern technologies have been introduced (Kondratenko, 2023). However, the analysis reveals that these efforts have been primarily focused on digitalizing administrative services, expanding the availability of free public Wi-Fi zones, and introducing basic elements of smart transportation. Taking these observations into account, it is deemed appropriate to further explore opportunities for integrating the most effective international smart city practices into the Ukrainian context, with special attention not only to large urban centers but also to small and medium-sized towns.

Conclusions. The operational concept of a smart city is becoming increasingly relevant, especially for Ukraine, a country undergoing war, profound socio-economic transformation, and seeking pathways to recovery. The integration of smart technologies into urban governance offers substantial potential to address urgent issues, such as efficient resource management, public safety, and environmental impact reduction. In contexts where resources are limited and rapid recovery is essential, the adoption of smart solutions becomes critically important. Moreover, the training of new professionals capable of utilizing these technologies is an indispensable element of the country's rebuilding process.

The smart city concept is currently implemented in more than 2,500 cities worldwide, creating a global momentum that Ukraine can leverage. Academic publications consistently emphasize the need to enhance urban-level public administration systems in Ukraine. Building smart cities within regional and territorial communities - through the automation of daily functions, effective territorial management, cost efficiency, and the rational use of natural resources - can serve as a catalyst for sustainable recovery and growth. At the same time, it must be acknowledged that Ukraine's smart city development significantly lags behind global trends, both in the speed of implementation and in the complexity of adopted technologies.

The formation of smart cities is a global trend, spanning continents and cultures. However, there is no universally accepted model of a smart city, and much depends on the commitment and cooperation of various stakeholders - businesses, governments, civil society, and individual citizens.

The findings of this study underscore that the smartification of cities is closely linked to the Human Development Index (HDI). Therefore, it is recommended that future public policy in community governance prioritizes a human-centered approach to urban and regional development. Focusing on the human dimension will contribute to increasing citizens' well-being and innovation potential, and will serve as a foundation for embedding smart infrastructure into society, especially in the context of post-war recovery and the socio-economic paradigm of sustainable urban development in Ukraine.

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