Urban ecological and digital transitions - concepts, challenges and policy perspectives

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Abstract. *The current global context is marked by a series of innovations that emphasized two extensive phenomena- the ecological and the digital transitions. The first one focuses on resource sustainability and is determined by the urgency of climate change, while the second one, the digital transition is driven by technological advancements and urban governance based on data. The present paper's aim is to establish the potential of the combined digital and ecological processes in revolutionizing urban systems. The duality should support inclusive, effective and environmentally responsible urban development in regards to public services and governance models.* ***Objective****: The main objective of the paper consists of initiating an integrative conceptual framework on the above-mentioned transitions and their impact on the urban environment. The study conducted at the level of the present paper analyses the ways in which cities can utilize emerging technologies in order to achieve ecological sustainability by adapting to climate changes and at the same time improving civic participation and public services.* ***Method****: The method of the research consists of a multidisciplinary exploratory analysis that combines results from environmental policy, digital advancements and urban studies. The conducted study explores the processes within both transitions and evaluates their impact on governance systems and urban infrastructure.* ***Results****: The analysis shows that the integration of digital tools as a support for ecological principles generate smarter urban planning and enhanced service delivery. Examples include intelligent transportation systems, adaptive lighting, environmental sensors, and platforms that promote participatory governance. The paper identifies key enablers and barriers to these transitions, including the need for digital inclusion, civic education, and flexible policy instruments.* ***Originality****: This study proposes the novel concept of the "smart ecological transition" as a framework for understanding how digitalization and sustainability efforts can converge in urban contexts. Its originality lies in the integrative approach that links Industry 4.0 technologies with circular economy models and urban resilience strategies, offering a forward-looking vision for city transformation in line with the sustainable development goals.*

Keywords*: ecological transition, urban digital transition, digital transformation, sustainable development, smart cities.*
JEL classification*: P0, P25, M31, O10, O33, O35*

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1. Introduction

The ecological transition is closely linked to sustainable development. The representative document of this concept is the UN Agenda 2030, which provides a set of 17 clear and quantifiable goals, as well as a 15-year action plan aimed at eradicating extreme poverty, combating inequalities, injustice and protecting the planet. The changes in the forms of production and consumption caused by the Industrial Revolution have increased attention to environmental problems. These were initially perceived at a local level, and then expanded to a global scale.

In Europe, the increase in deforestation activities has led specialists to take measures to preserve nature based on the idea that they will represent a danger to future generations. These actions have reinforced the concept of global sustainability in the environmental field (Du Pisani, 2006).

The concepts of green economy and green growth represent the core of sustainable development or sustainability. Green economy focuses on an economic system in which ecological sustainability and social well-being are emphasized. The second concept, green growth refers to a sustainable economic growth that results from both ecological and social inclusion principles. The amalgamate of green growth and green economic policies can help meet the Sustainable Development Goals, while also enhancing societal well-being. The green economy represents one of the most significant global developments since the 1970s. The internalization of environmental externalities and the polluter pays principle have been proposed as solutions to environmental problems within the framework of sustainability (Purkis, 2020).

Promoting the circular economy represents a key priority for European Union policies given to the opportunities brought by it. These include the creation of new, durable competitive advantages at the European level and economic transformation. Designing reusable items and avoiding production waste are essential to achieving these objectives. Through the integration of social, economic, and environmental factors, urban regeneration is portrayed as a significant role in urban planning. The purpose of these is to improve resilience and sustainability at the city level.

Novelty services that are dedicated for urban health and sustainability pose challenges in the integration within urban planning and policies. This is given to the intricate human-natural systems interdependency and to the digital technologies. The digital transformation of the urban environment is regarded as an essential component in achieving sustainable development and enhancing competitiveness at the municipal level, within the current context of rapid technological advancements that occur at the global level. The infrastructure, resource management, and services offered to urban dwellers can all benefit greatly from the digitalization process.

Although the digitalization process brings numerous benefits to cities, recent years have witnessed that the rapid expansion of urbanization has led to increased energy consumption and greenhouse gas emissions. These developments have contributed to significant environmental risks and the emergence of climate-related issues. Despite the considerable rise in urban pollution, it is widely acknowledged that disruptive new technologies have had a substantial impact on both economic and social development (Xinfa & Jinglin, 2022).

Digital transformation represents a paradigm shift that affects industries, companies, and urban operations. It plays an essential role in social development, involving the use of emerging technologies to optimize both economic and social processes. The effective integration of these technologies in cities can lead to reduced resource consumption, waste minimization, and maximized operational efficiency (Ferraris et al., 2019). Digital transition (Xiao et al., 2024) is not a novel concept in academic literature. It has been studied since the 1950s, when organizations began employing digital technologies to support operational and strategic exchanges across sectors. The digital transition represents an uninterrupted process involving new technology adoption.

The urban environment has also benefited from the integration of emerging technologies. Among these, the most important are the following: Artificial intelligence (AI), Big Data and Internet of Things (IoT).

These disruptive technologies play a key role in various activities such as waste management and reducing the effects of pollution. There is a need to adopt emerging technologies within urban activities in order to deliver superior services to the residents (Rosario & Dias, 2022).

Given the growing significance of both digital and ecological transitions in shaping contemporary urban development, this study sought to identify the effects of these processes on the societal pillar. The aim was to examine their potential to reshape governance models, civic participation, and sustainability practices within the urban context. Accordingly, the research was guided by the following central question: In which way can the convergence of digitalization and ecological transition promote a sustainable and resilient urban system?

2. Literature review

Pillars of the ecological transition

Sustainable development embodies two important notions, which are environmental economy and ecological transition. The Green Deal represents the latter, while the Sustainable Development Goals are the best example of the former. A shift to a resilient economy and a green climate is the goal of both the green economy and the green transition, which are closely related to sustainability.

According to Houssam et al (2023) a common link between green economy and circular economy consists in the principle of transforming the present economic model in order to attain sustainability. This will eventually lead to the occurrence of an ideal economic system which is environmental-oriented.

The term "green economy" refers to an economic strategy that may guarantee growth and development while simultaneously raising living standards. To put it simply, this idea aims to improve social fairness while reducing ecological poverty and environmental dangers (Iqbal et al., 2025). The following are important ideas that underlie the ecological transition: renewable resources, the electrification of transport, smart buildings, the agro-ecological model.

Renewable resources are utilized in order to achieve environmental objectives at the European level. Increasing investments in renewable, non-polluting, and natural energy sources can help achieve this (Ullah et al. 2021). One of the primary causes of air pollution is the transportation industry. Investments in urban, regional, and electric transport mobility are required to meet the 2030 target of 6 million electric vehicles (Rehman et al., 2023). The employment of cutting-edge technologies in the energy supply chain is referred to as "digital energy" (Khan et al. 2021).

Smart buildings are automated and intelligently managed with the goal of achieving energy system efficiency (Hernández et al., 2024). Self-regeneration is a feature of the circular economy. There is no waste because all residues are viewed as resources in this sense.

This represents a fresh perspective on logistics, production, and consumption. (Kopnina, 2019). The agroecological model refers to reducing the negative impact of pesticides on health and the environment and promotes organic agriculture (Tittonell, 2020).

Ecological transition in Europe: strategies, challenges, and cooperation

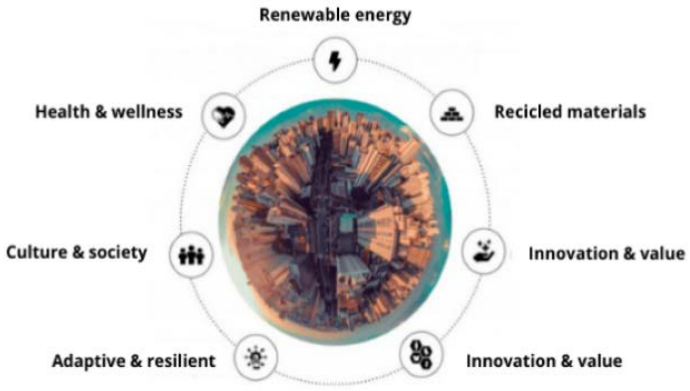
The Green Deal implemented at the European Union level follows an eager green transition by reducing gas emissions, promoting carbon neutrality and protecting biodiversity, as well as increasing the investments made in green technologies. In order to be achieved, this EU level transition should include long-term investments in what regards low-carbon technologies, as well as R&D investments in order to accomplish the sustainable development goals (SDGs). The energy transition underway both in Europe and globally should align with the broader green transition that is struggling to get going. The green transition looks at the limits of the planet and aims to establish measures to reduce the harmful effects caused by different factors (Ciliberto et al. 2021).

The European ecological transition relies on the national governments' and EU institutions' ability to cooperate in order to reach an agreement to maintain the Green Deal trajectory. An example of policy within the European Union's Biodiversity Strategy is depicted by the Nature Restoration Law (2024) whose objective is to restore natural resources and extend biodiversity. Thus, it contributes to the mitigation of the climate change effects and to increase Europe's overall resilience. The previously mentioned elements are also part of the greater European Green Deal plan which aims to transform Europe into the first climate-neutral continent.

The primary circular city dimensions that have been estimated from the literature are represented by urban scales (Muscillo et al. 2021). Expanding the urban aspect of circular city initiatives supports the green energy shift from "building" to "neighborhood."

This direct proportionality link is a valuable addition that helps steer programs for regeneration. One of the Recovery and Resilience Plan's (PNRR) strategic priorities in Italy is the use of recycled materials, which gives priority to the following important areas: digitalization, innovation, competitiveness, tourism and culture, green revolution and ecological transition, sustainable mobility infrastructures, research and education, cohesion and inclusion and health.

Figure 1. The pillars of the circular economy in relation to the three urban scales



Source: Balletto et al. (2022).

Both directly and indirectly, these regions come together to form the circle city (Balletto et al., 2021). In order to facilitate the nation's green and digital development, Italy authorized the PNRR in 2021 as a plan to revive its economy following the COVID-19 epidemic (European Commission, 2021).

Urban metabolism refers to the cities' behaviour that is similar to living organisms as they consume resources from surroundings and produce waste (Kennedy et al. 2010). The resources consumed by cities are materials, food, water and energy. After they are metabolized, they turn into waste under the form of wastewater, greenhouse gases and organic and inorganic solid waste. Today's city metabolism follows a linear pattern, meaning that the inputs are used to keep all the functions working and after that they are disposed of as waste. However, this model not only increases resource consumption, but also waste, thus pressuring environmental integrity. In this way, finite natural reserves are depleted and waste is produced in quantities that cannot be absorbed by the environment without any damage.

The use of emerging technologies in the digital transformation of cities

In its broadest sense, digital transformation is a multifaceted idea that may be used to integrate digital technology to change urban environments, governance structures, economies, and societies. As mentioned before, a number of technologies, such as big data, cloud computing, the Internet of Things, and artificial intelligence, are currently being used in the digital transformation of cities (Appio et al., 2021).

To improve urban operations, several public administrations around the world have been using digital technologies more and more in recent years. Based on cutting-edge technologies, smart city development (Omrany et al., 2025) can maximize resource utilization and advance sustainable urban growth. Initiatives for urban digital transformation provide creative answers to the problems of urban growth in a digital economy (Jiang et al., 2023).

A key point to emphasize is that urban digital transformation should be understood as a phased process that involves the application of disruptive technologies across various urban sectors. Furthermore, the focus should not rest solely on the types of technologies implemented, but also on the strategies guiding their use. These technologies must be employed to stimulate comprehensive urban

development, thereby contributing to long-term sustainable growth. Urban digital transformation should aim not only at immediate economic gains but also at: increasing employment opportunities, improving resource efficiency, enhancing economic inclusion, modernizing industrial structures, reducing environmental pollution (Guo & Ma, 2023) and promoting sustainable societal development.

All these aspects contribute to long-term urban growth and the advancement of society as a whole (Yu et al., 2025). Within the urban digital transformation process, data is considered a central element. The marketization of data (Data Factor Marketization – DFM) plays a critical role in this transformation and is of particular importance for ecological urban development.

Previous studies have shown that digitalization significantly supports urban environmental sustainability, with digital technologies contributing to environmental quality improvements and to the economic and social development of cities (Li et al., 2024).

The role of emerging technologies in urban development

Disruptive technologies bring impressive opportunities for all the urban development pillars. Technologies such as Big Data and Artificial Intelligence can help policymakers into making informed decisions that will protect ecosystem services (ESs) and biodiversity. This improves urban planning's accuracy and effectiveness (Scowen et al. 2021).

When viewed holistically, emerging technologies are essential for advancing industrial modernization, technical innovation, and the creation of new energy sources. According to Song et al. (2024), digital technologies are commonly used to lower carbon emissions in urban settings, which helps to lessen pollution in places with a high population density. Furthermore, their implementation promotes the development of new sectors, producing creative services and business prospects (Qi & Xu, 2020).

One major objective of urban digital transformation is to implement emerging technology-based methods aimed at protecting the environment. This includes the adoption of advanced technologies and the deployment of sensors in smart cities to monitor air and water quality and enhance the efficiency of urban resource usage (Diguet & Lopez, 2020).

New approaches focus on the ability of urban systems to adapt to changing conditions and adjust their function to them in order to remain efficient. Thus, urban regeneration initiatives aim to create strategies that increase urban resilience and address the critical weaknesses. These can be done with the help of data-driven approaches based on disruptive technologies.

However, this change is not solely driven by advancements in technologies and methods; it also influences societal values. Therefore, appropriate design and governance are required to conceptualize the city as a living organism.

The emergence and development of Cities 4.0

The rise of Industry 4.0 has influenced how urban activities are managed, leading to the emergence of "Cities 4.0", a new model of smart cities. These cities aim to integrate emerging technologies to optimize urban systems and improve residents' quality of life. It is important to note that digital transition encompasses more than just the adoption of technologies; it also requires a fundamental reconfiguration of urban governance structures.

In smart cities (Anthony Jnr, 2020), disruptive technologies play a significant role in shaping public policy. Cities 4.0 harness citizen engagement, connectivity, digital technologies, and data to improve urban quality of life. Moreover, they are vital for increasing productivity and promoting sustainable development.

The concept of City 4.0 refers to urban areas that have implemented emerging technologies to transform local public services and generate sustainable, desired outcomes economically, environmentally, and socially for all stakeholders (Yigitcanlar et al., 2024).

Digital platforms are essential for gathering and evaluating vast amounts of data in the urban setting, as well as for maximizing infrastructure and services (Prabowo et al., 2023). High-quality municipal services can be provided via both public and private platforms.

Advanced urban platforms that incorporate a wide range of disruptive technologies can be developed and used by cities to improve sustainability, operational efficiency, and the general standard of living in urban areas. The following are important technologies used in these platforms: Internet of

Things (IoT), Artificial Intelligence (AI), Big Data Analytics, Cloud computing,5G networks, Blockchain technology, Augmented reality (AR), Virtual reality (VR), edge computing and robotics and automation;

These technologies help improve urban mobility, increase energy efficiency, and enhance public safety. However, the implementation of such platforms also raises vulnerabilities related to personal data processing and regulatory compliance. In recent years, cognitive city platforms have been introduced in certain urban areas, utilizing artificial intelligence and machine learning for real-time management of urban activities.

Additionally, smart cities (de Bem Machado et al., 2023) employ IoT systems and drones to monitor pollution and facilitate faster, more efficient waste management. All of these technologies support sustainable urban planning (de Genaro Chiroli et al., 2025).

3. Methodology and data

The study conducted within this research aimed to analyze the connection between the ecological and digital transitions at the urban level. The research consisting of an analysis of the specialty literature emphasized concepts, challenges and policy perspectives in regards to the above-mentioned transitions and smart cities. The findings provided an integrated perspective on the manner in which urban sustainability can be achieved with the help of both digital instruments and ecological transition. In what concerns novel technologies, they are able to address various challenges from climate change to efficient resource utilization.

4. Research results and comments

Urban sustainability refers to a city's capacity to maintain economic, social, and environmental well-being while simultaneously meeting the needs of current and future citizens (Shi & Lu, 2024). Building a sustainable economy inherently involves both digital transformation and innovation within the urban environment.

Emerging technologies possess the potential to address major challenges related to climate change, efficient resource utilization, and the reduction of social inequality. In this context, digital technologies play an increasingly important role, significantly contributing to the development of urban environments and enhancing the management of urban operations (Pricopoaia et al., 2025). The intelligent application of digital technologies in sustainability strategies can: lower resource consumption, minimize waste generation and enhance the effectiveness of administration.

At the city level, digital transformation is a complicated process that necessitates large expenditures in material and human capital to meet the intended goals. It provides a number of advantages for sustainable urban living. However, employing emerging technologies comes with a variety of challenges, particularly when it comes to integrating them. The following are common outcomes of the digital economy's expansion and the adoption of disruptive technologies: increased energy consumption, resource depletion and higher volume of electronic waste.

Moreover, it is expected that as emerging technologies become more deeply embedded in daily life, the digital ecological footprint will proportionally increase. These developments contribute to greater energy use, higher carbon emissions, and continued reliance on fossil fuels (Goel et al., 2024).

5. Conclusion

The past period of time was marked by shocks and uncertainties that determined the European Union to take measures. These consisted of a strategic agenda for the 2024-2029 period that seeks a democratic, secure and competitive Europe. In order to accomplish these ideals, a complex set of policies has been launched by the EU as an integrated approach addressing the three main societal pillars (economic, social and ecological) having the environmental dimension as the central piece. The objective of these policies is a climate neutral and resilience-oriented development.

Environmental initiatives (natural capital protection, biodiversity enhancement, climate change issues) consist of the main objective in the reinforcement of social, economic and territorial cohesion.

For a long time, urban planning faced various difficulties such as the financial crisis of 2008, and the pandemic in 2020. These led to inequalities, democratic gaps and an increase in social exclusion. The rapid urban growth that has shown in the past decades caused a contrast between competitive development and the socio-environmental issues.

The global ecological transition is significantly influenced by the ecological transition occurring at the local level. In order to lessen waste creation and the depletion of environmental resources, this changes the current linear urban metabolism into a circular metabolism that seeks to reduce material inputs (food, water, and goods). This can be achieved with the help of the circular economy principles that maximize the utilization of renewable resources and energy efficiency, as well as redesign urban services.

The convergence of ecological and digital transitions represents a fundamental paradigm shift in shaping the future of European cities. The emergence of concepts such as the green economy and green growth has enabled the European Union to adopt more sustainable approaches in response to recent crises, promoting green technologies and energy efficiency across key sectors like construction, automotive, and manufacturing.

The groundwork for long-term initiatives aimed at lowering greenhouse gas emissions and converting the EU into a sustainable society has been established by programs like the Europe 2020 Strategy. The urgency of resource efficiency and environmental responsibility is highlighted by the move toward renewable energy sources and circular economic models.

At the same time, the digital transition of urban environments should not be seen solely as a modernization tool, but rather as an essential response to the complex challenges cities face today, ranging from climate change to resource scarcity and social inequality. Emerging technologies contribute significantly to the optimization of public services, pollution reduction, and the overall improvement of urban quality of life. However, the success of digital implementation relies heavily on the strategic vision of local authorities and their capacity to promote inclusive governance through collaboration with the private sector and civil society.

Ultimately, both transitions must be understood not as parallel developments, but as interdependent processes that reinforce one another. Together, they shape a new urban model, resilient, intelligent, inclusive, and sustainable. Achieving this vision requires coordinated action, long-term policy commitment, and an unwavering focus on the common good.

Moreover, it is important to emphasize that ecological and digital transitions are not only social or environmental imperatives, but also carry profound implications for the economic environment. By promoting innovation, creating new market opportunities, and encouraging competitive growth, these processes have the potential to reshape urban economies. At the same time, they may encounter structural barriers, ranging from financial constraints to regulatory gaps, which need to be carefully addressed to ensure a fair and efficient transformation.

Considering the importance of these transitions, future research should integrate both qualitative and quantitative approaches. On the one hand, in-depth interviews and focus groups with national experts could offer valuable insights into how such transitions can be implemented at the city level, as well as the obstacles that may arise in practice. On the other hand, large-scale quantitative surveys among citizens would provide essential information about how people perceive the benefits of digital and ecological measures in their everyday lives, and the extent to which these innovations have improved the quality of urban living.

Such empirical investigations would not only reinforce the theoretical foundations laid out in this article, but would also generate a clearer, evidence-based perspective for the future. They would allow policymakers and stakeholders to design strategies that maximize the benefits of ecological and digital transitions, while minimizing risks and ensuring inclusive, sustainable economic development.

Authors' contribution: *Introduction, S.A.M., R.A.-C., I.R.; Literature review, S.A.M., R.A.-C.,I.R.; Conclusion, S.A.M., R.A.-C., I.R.*

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