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NEW CHALLENGES FOR XXI CENTURY CITIES

Global warming, ageing of population, reduction of energy consumption, immigration flows, optimization of land use, technological innovation

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The cover image shows older people climbing Via Raffaele Morghen's stairs in Naples (Source: TeMA Journal Editorial Staff).

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Planning the transition of cities. Innovative research approaches and trajectories

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Abstract

In light of the ecological, digital, and just transition envisaged by the EU for reaching the ambitious Green Deal objective by 2050 and its inherent complexity, this paper focused on the nexus between Ecosystem Services and Key Enabling Technologies as a potential and significant element for the future development of promising research trajectories in urban planning. The transition of cities has become a top priority in academic and policy debates, attracting increasing attention from scholars and policymakers. Ecosystem Services are crucial elements for human well-being, and despite their inclusion in urban plans, there are still issues to address requiring innovative research approaches and trajectories to explore for planning the ecological, digital, and transition of cities. Two main elements are explored in this contribution: 1) the centrality of ecosystem services and the potential of related key enabling technologies for the planning of the ecological and digital transition of cities; 2) the current ecosystem services assessment analytical approaches characterized by a spatially explicit perspective presenting relevant implications for the planning dimension. As a result, the paper outlines a research-based conceptual framework aimed at defining promising innovative research approaches for new trajectories to be explored in urban planning.

Keywords

Transition; Ecosystem services; Key enabling technologies; Data-driven planning approach; Urban planning and governance

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1. Introduction

The paper aims to outline possible innovative research trajectories to explore for planning the transition of cities, which are called to face severe pressures and challenges, such as climate changes, energy issues, and poverty, underscoring the urgency for more sustainable cities (Salat & Bourdic, 2012; Giannakidou & Latinopoulos, 2023). The European Union (EU) has introduced the Green Deal (EU, 2019) as a strategic framework aimed at propelling the transition towards a carbon-neutral economy, decoupling economic growth from resource exploitation (EU, 2019). Simultaneously, it endeavors to "protect, conserve, and enhance the EU's natural capital, and protect the health and well-being of citizens from environment-related risks and impacts" with a commitment to ensuring a just and inclusive transition (EU, 2019). Such a direction towards the definition of a more sustainable path implies to rethink EU policies across sectors for the supply of clean energy and at the same time safeguarding natural ecosystems, also exploiting the potential of new technologies and digital transformation, which assume significance in catalyzing such a transformative shift for the Union (EU, 2019). The envisioned ecological and digital transition, permeating all economic sectors, is calling also for a new demand for sustainability in cities, in which restructuring processes find their synthesis and where the balance between a more sustainable economic development and human well-being emerge as central element for their future development. Consequently, it is deemed significant to comprehend the intricate dynamics interlinking urban changes with socio-ecological-technological transformations to gain insights into the nexus between ecological integrity and human well-being for the prospective development trajectory for cities (Alberti et al., 2018). In light of the accelerated pace of worldwide urbanization processes (Ahern et al., 2014; Lai & Zoppi, 2023), the demand for ecosystem services (ESs) and natural capital is steadily increasing (Gómez-Baggethun & Barton, 2013), and addressing the challenges related to sustainability in cities claims for new approaches in urban planning and design (Ahern et al., 2014; Mazzeo & Polverino, 2023). Urban transformations heavily affect natural ecosystems and the production of their services, (Lai & Zoppi, 2023), and preserving natural habitats and reducing pressures on natural ecosystems is significant for protecting the territory and urban areas from endogenous and exogenous fragilities (Caprari & Malavolta, 2024). The relevance of the ESs topic is growing in the academic and policymaker's arena, especially concerning its inclusion in urban planning, deemed crucial for promoting sustainable urban development (Cortinovis & Geneletti, 2019; Cortinovis et al., 2020; Tan et al., 2020; Lai & Zoppi, 2023) and resilience (Claron et al., 2022). The concept of Ecosystem Services (ESs) has significantly contributed to urban planning by integrating diverse fields of knowledge to assess the benefits humans derive from nature (Marques et al., 2022). While it is largely explored in the ecology and increasing in the economic assessment fields, its presence in the urban planning literature deserves more attention (Qiu et al., 2022). One of the most significant features of ESs is their systemic perspective, which views sustainability as a complex phenomenon rather than just an environmental concern by incorporating cultural, social, and economic dimensions (Marques et al., 2022). This interdisciplinary approach encompasses a range of research areas and methodologies, including those within urban planning related to the ESs concepts such as Green Infrastructures, Ecosystem-based Adaptation, and Nature-based solutions (Marques et al., 2022) land consumption reduction, the renaturalisation of territories, the production exploitation of renewable energy sources, and adaptation to the effects of climate change (Mazzeo & Polverino, 2023). Despite the relevance of the ESs concept, Qiu et al. (2022) have identified a set of knowledge gaps and challenges in linking ESs research to urban planning: a gap between science and practices, a gap between science and policy, and a gap in urban green governance. On the one hand, the efforts to protect natural ecosystems and biodiversity are at the top of the policy agenda, as in the EU case with the EU Biodiversity Strategy for 2030 (EC Eurostat, 2021). Conversely, rapid urbanization processes negatively affect biodiversity and the ESs offered for human well-being (Sirakaya et al., 2018). Although urban plans already include ES-related actions and different tools for their implementation, there are still issues to address (Cortinovis & Geneletti, 2018; Geneletti et al., 2020): knowledge transfer into planning practices;

embedding ES information into planning processes; usable methods to assess urban ES at a relevant scale while accounting for multi-functionality of ecosystems analyses of ES demand in plans; and ES are not considered a strategic issue in urban planning. Including ESs in urban planning – which is an example of a decision-making process where the complexity of policy questions is addressed – is central to the promotion of sustainable urban development and then for city transition (Cortinovis et al., 2020; Qiu et al., 2022).

Here, it is argued that planning the transition should harness the potential of key enabling technologies (KETs) and place ESs as central element for a sustainable transition of cities and territories (Cortinovis & Geneletti, 2018). Such an approach is supported by recently developed perspectives that emphasize the relevance of ESs knowledge in urban planning as a valuable strategy for tackling complex challenges in contemporary urban development (Cortinovis et al., 2020). At the same time, sustainable transformative development is calling for a new, robust science of cities to give urban policymakers the body of knowledge necessary to address the current issues (UN, 2019). This perspective refers to the advancements of technologies and the emergence of data-driven approaches, central in the so called and emerging "*urban science*" or "*science of cities*", in which data and advanced data-analysis methods and techniques are exploited to better understand real-world phenomena (Bettancourt, 2021). This new approach is given by the rapidly expanding computational science field and its potential connection with urban studies that are shaping the so-called urban informatics, which applies big data and computational methods to urban management, policy, and planning (Kontokosta, 2021), and that can provide valuable resources to comprehend better the complex relationships between cities and ecosystems (Koc & Acar, 2021). The centrality of technologies and data is also emphasized by EU policies on KETs, deemed pivotal for the future of the EU (EU-EPRS, 2021). In a recent EU parliament study six relevant emerging technologies for the future of the Union have been outlined (EU-EPRS, 2021): advanced manufacturing, advanced (nano) materials, Life-science technologies, Micro-nano electronics and photonics, Artificial intelligence, Security and connectivity technologies. Various EU programs, such as Horizon Europe prioritize KETs, with Big Data and Artificial Intelligence technologies considered cross-cutting elements among the nine identified KET areas, namely: Manufacturing technologies, Key digital technologies, Advanced materials, Artificial intelligence and robotics, Next generation internet, Advanced computing and big data, Circular industries, Low carbon and clean industries, Space (EU EPRS, 2021).

Therefore, the main research questions are the following: How can emerging key enabling – and associated – technologies enhance the knowledge on ESs for the advancement of urban planning practice in facilitating cities' transition towards sustainability and increase their resilience? Furthermore, what could be the implications of such a data-driven perspective for planning? These research questions encompass the exploration of cutting-edge technologies and their potential to support the assessment and management of ESs for cities from a research-based perspective, thereby promoting interesting research trajectories to explore. Two main elements are explored in this contribution: 1) the centrality of ecosystem services and the potential of related key enabling technologies for the planning the ecological and digital transition of cities; 2) the current ecosystem services assessment analytical approaches characterized by a spatially explicit perspective presenting relevant implications for the planning dimension.

Given the raising relevance of ESs for urban planning, and the raising awareness on the potential of key emerging technologies in addressing contemporary challenges, the paper analyzes the current integrated and comprehensive ESs assessment analytical approaches characterized by spatially explicit perspectives. Such methods are the UN SEAA-EA (UN, 2021), the EU Mapping ES (EC, 2013; EC-JRC, 2020), and the EU INCA Project (EC-Eurostat, 2021). The aim is to outline a research-based conceptual framework characterized by a data-driven planning approach for managing the transition centered on ES by exploiting the potential of KETs for planning. This perspective is articulated in three main drivers, operating at multiple scales and dimensions but interconnected by the data-driven planning perspective centered on ESs and KETs.

These research drivers contribute to defining promising research trajectories to explore and provide interesting insights and implications for the planning process by envisioning data-driven planning centered on ESs for future urban and territorial transformation processes.
The paper is structured as follows: The next section emphasizes the relevance of ESs and KETs for planning cities' transition by outlining the main areas to explore in relationship with the planning dimension, highlighting the relevance of the spatial dimension, spatially explicit information, and KETs in addressing this topic. The third section outlines the main spatially explicit approach characteristics for the mapping and assessment of ESs in the EU. The discussion and conclusion section frame the results into a conceptual framework for an innovative data-driven planning perspective aimed at the transition of cities by defining promising research drivers to explore and the overall implications for planning.

2. The EU overall policy framework for the ecological and digital transition towards a more sustainable future

The EU Green Deal is reshaping the policy framework for the Union's future, emphasizing the ecological and digital transition paths toward sustainability (EU, 2019). However, it is essential to recognize that connecting and aligning these two transitions can be challenging, as they have different natures and dynamics (Muench et al., 2022). While the green transition is driven by the urgent need to achieve climate neutrality and sustainability through substantial political and social efforts, the digital transition is an ongoing process of technology-driven change, with a significant role played by the private sector. Given the potential risks, a primary challenge for the EU is to ensure that both the ecological and digital transitions are fair, inclusive, and just (Muench et al., 2022). Within this overarching framework, cities play a fundamental role in the transition process, requiring reevaluating their urban development strategies and planning tools to address ongoing changes and challenges. Both transitions are integrated into EU policies and priorities. The ecological transition aligns with EU goals to protect the environment, minimize climate-related risks, and safeguard human health and biodiversity. The European Green Deal, for instance, aims to position Europe as the world's first climate-neutral continent by promoting cleaner energy sources and green technologies (European Commission, 2023). This initiative responds to climate change and seeks to preserve and enhance the EU's natural capital while safeguarding citizens from environment-related risks and impacts. This is achieved by reducing emissions and decoupling economic growth from resource consumption (European Commission, 2019). At the same time, digital transformation processes and tools are deemed important to achieve the objectives of the EU Green Deal (European Commission, 2019). The fast-paced development of technologies and tools in big data and artificial intelligence unveil not only the not-yet well-defined risks of such unexplored areas but also the potential implications for everyday people's lives. Concerning cities and urban planning, such a technological wave, thanks to the amount of data generated in cities, is already deploying its potential in terms of implications. A recent study of the EU Parliament (Pellegrin et al., 2021, 19) outlined how AI in cities is mainly related to "data collection, interpretation, and analysis in support of policy decision-making and planning and improved delivery of services of public interest." Specifically, its employment in cities is mainly characterized by a data-analytics approach (Pellegrin et al., 2021, 19). This interpretation follows the recent scientific debate in the urban studies area on the role of (big) data and new technologies in the advancement of the so-called urban data science (or science of cities) with the emergence of urban analytics (Batty, 2019; Bettencourt, 2021; O'Brien, 2022), favoring the development of innovative data-driven approaches for the better understanding of cities complex dynamics and more up-to-date and tailored information for decision-makers, and the management of cities. In this overall policy framework, characterized by the ecological and digital transition, we focused on the nexus between ESs and KETs as a potentially significant element for the future development of promising research trajectories in the urban planning field for planning city transition.3. The centrality of ESs and Key Enabling Technologies for planning cities' transition. Cities depend on natural ecosystems and their components to sustain long-term human well-being (Gómez-Baggethun & Barton, 2013) thank to the services (ESs) they provideES (Bezák & Lyytimäki, 2011; McPhearson et al., 2014). ESs are commonly defined as the direct and indirect contributions of ecosystems to human well-being outlining a complex set of relationships between humans and nature (Cortinovis et al., 2020; Tan et al., 2020). Such a complexity materializes in cities that contain approximately 70 percent of the world's population and will produce 85 percent of global economic output by 2050 (UN, 2019). Specifically, ESs "refer to those ecosystem functions that are used, enjoyed, or consumed by humans, which can range from material goods (such as water, raw materials, and medicinal plants) to various non-market services (such as climate regulation, water purification, carbon sequestration, and flood control" (McPhearson et al., 2014, 504). Although the ESs concept was initially developed between the 1960s and the 1970s to highlight the importance of the biodiversity of ecosystems for humans, only during the 1990s was the concept significantly explored for the understanding of relations between ecosystem functions and human welfare in urban areas (Bezák & Lyytimäki, 2011). Since the work of the Millennium Assessment in 2005, ESs classification has been further detailed through several studies and approaches, and a finalized agreed classification of ESs at the international level has not been produced yet (UN, 2021). The UN SEEA-EA, following the standard classification developed about ESs classification, provides three main categories of ES (see Tab.1):

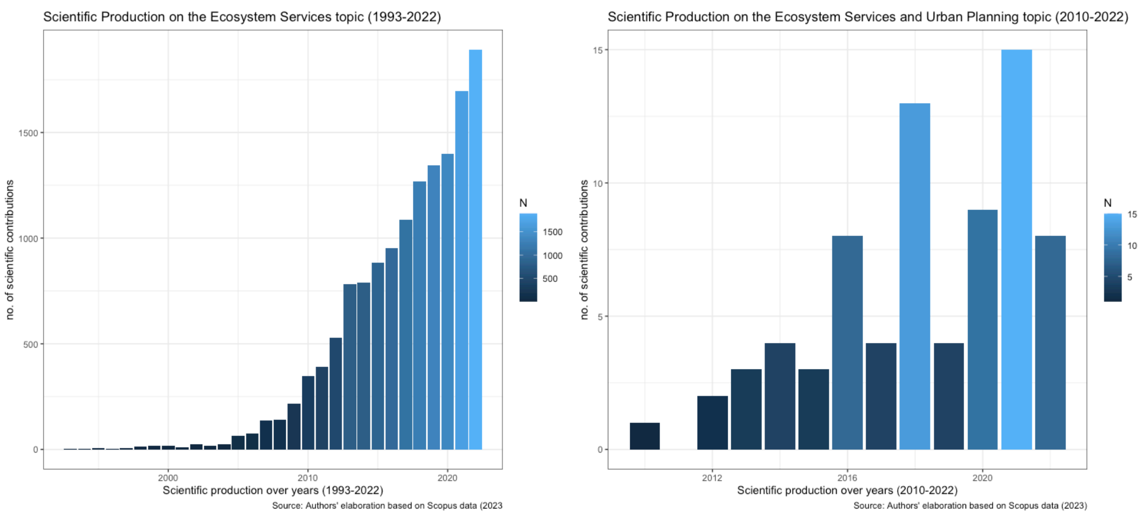
i) provisioning services;

ii) regulating and maintenance services;

iii) cultural services (UN, 2021).

Ecosystem Service	Description
Provisioning Services	Represent the contributions to benefits that are extracted or harvested from ecosystems
Regulation and maintenance services	Result from the ability of ecosystems to regulate biological processes and to influence climate, hydrological and biochemical states, and thereby maintain environmental conditions beneficials to individuals and society
Cultural Services	Represent the experiential and intangible services related to the perceived or actual qualities of ecosystems whose existence and functioning contributes to a range of cultural benefits

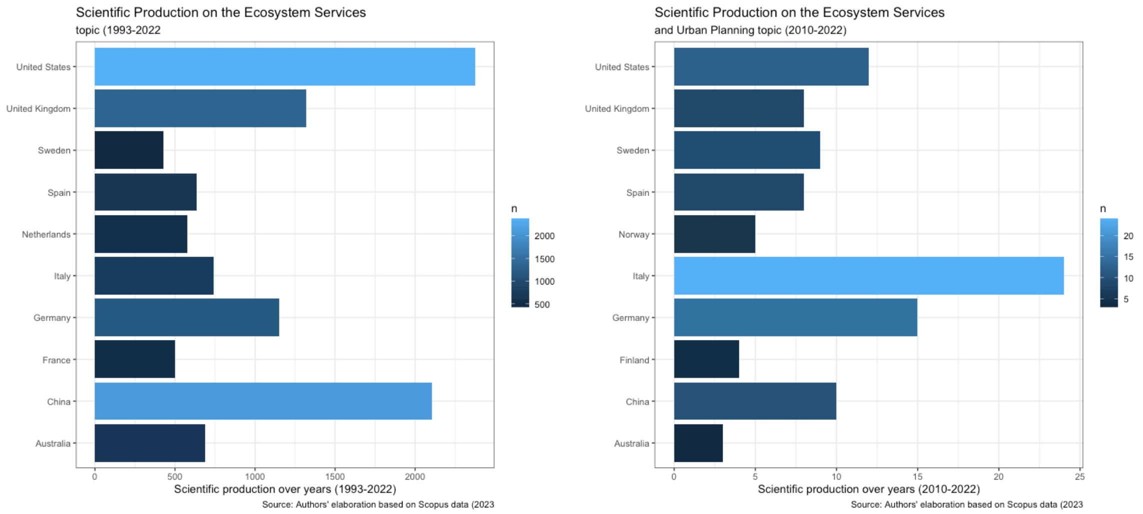
Tab.1 Description of the main ES categories. UN SEEA-EA (UN, 2021, 130)



(a) **(b)**

Fig.1 Scientific Production on the ES 1993-2022 (a) and on the ES and Urban Planning 2010-2022 (b)

Fig.1a shows how the ESs topic is gaining interest in the academic arena, with a scientific production that increased constantly in the period 1993-2022. At the same time, in the last decade, the scientific production on the nexus of ESs and urban planning has increased (Fig.1b). The first sees a concentration in the United States and China (Fig.2a), while the second, in a different timeframe – sees most of the scientific production in Italy (Fig.2b).



(a) (b)

Fig.2 Scientific Production on the ES 1993-2022 by country (a) and on the ES and Urban Planning 2010-2022 by country (b)

ESs are central to the planning discourse for at least three main reasons (Cortinovis et al., 2020; Tan et al., 2020): first, their provision depends on the availability and spatial distribution of ecosystems and their components which depends on land-use allocations assigned by the urban planning process (supply); second, by defining the land use and its spatial arrangements, urban planning also determine population distribution and urban functions shaping the demand for ESs; third, by defining the physical and institutional arrangements of the city, urban planning contribute to the definition of who can benefits from urban ESs (management). Moreover, urban areas are crucial for the ESs investigation as they are the place where the majority of ESs are consumed and the majority of pollution and waste are produced (Mazzeo & Polverino, 2023) ESs in cities deserves more attention, and a set of aspects on ESs planning in cities are not adequately covered by research activities (McPhearson et al., 2014). Such aspects can be synthesized in the need for more knowledge on the ESs status in terms of mapping/assessment, the inequalities deriving from the mismatch between the spatial distribution of ES supply and demand in cities, and the need to operationalize ESs frameworks for a better inclusion of biodiversity principles into governance practices, sustainability, and resiliency policy initiatives (McPhearson et al., 2014). The ESs assessment and evaluation across space and time requires a multidisciplinary approach, as integrating different mapping and assessing methods can represent the response to the challenge of real-world policy questions (Cortinovis et al., 2020). The integration of ES into urban planning frameworks can be facilitated by sophisticated data and innovative ESs analysis methods and technique, which allows the exploration of the potential of ESs mapping to inform urban and regional planning policies (Claron et al., 2022). Recent research approaches have highlighted the emergence of a need for renewing urban planning cognitive tools through GIS digital geographical processes and geospatial analysis techniques (Capriati & Malavolta, 2024). At the same time, the empirical identification and assessment of ESs relationship with urban land cover and uses emerge as a topic to address (Lai & Zoppi, 2023), together with the spatial identification of their variation in cities (Giannakidou & Latinopoulos, 2023), the implementation of Nature-Based Solutions in cities for climate changes adaptation (Mazzeo & Polverino, 2023) and circular dynamics by focusing on urban metabolism (Federico et al., 2023), and also the potentials related to the co-creation activity in contributing for a more sustainable city (Łaźniewska et al., 2021). Some of the existing challenges related to a better comprehension of ESs (quantification, mapping, assessment, dynamics) can be addressed by the recent technological advancement in Machine Learning (ML) and Big Data (Manley et al., 2022), which can result helpful in mitigating, adapting to, and managing the pressures cities are exposed to. Recently, ML methods and techniques have improved, allowing big data to be manipulated and analyzed easily and quickly (Willcock et al., 2021). Concerning the ESs topic and its inclusion in urban planning, ML techniques – for example through the application of supervised (classification, regression) and unsupervised (clustering) and big data can be useful tools to address the challenges of data availability, understanding and estimating uncertainty, and the better understanding of socio-ecological aspects of ecosystems and (Manley et al., 2022). The application of new and alternative relevant big databases, the increasing size and resolution of big data, and the availability of ML algorithms for better understanding the complex dynamics of ESs can provide useful tools for filling the gaps in the current knowledge of ESs (Manley et al., 2022). Such relevance is clearly outlined in the EU priorities for the 2021-2027 programming period. KETs and associated technologies are deemed significant for an interconnected, digitalized, resilient, and healthier Europe and increase its competitiveness in the world economy (European Commission, 2023). The OECD has recently investigated the supporting role of emerging technologies in measuring ESs by emphasizing two main elements (Van Bodegom et al., 2020):

i) the importance of new technologies in providing high-resolution assessment at the local scale, which can result useful for the local decision-making processes,
ii) new technologies can increase the ESs assessment tools with respect to the key criteria for the applicability and adoption in the decision-making process (credibility, salience, legitimacy, and feasibility), and to whom indicators selected for the measurement of ES should be aligned (Van Bodegom et al., 2020).

At the same time, the report outlines three main areas of emerging technologies useful in supporting ESs measurement and assessment activities (Van Bodegom et al., 2020):

a) higher resolution local input data;
b) data science for locally fit transfer functions;
c) insights in trade-offs and synergies among ecosystem services.

From the overall framework developed by the OECD (Van Bodegom et al., 2020), it is possible to outline preliminary areas of investigation related to KETs to explore for data-driven planning of cities transition centered on ESs:

1) Remote Sensing technology and methods: useful for monitoring the biophysical parameters and metrics with the potential to address the basic issues of spatially quantifying the ESs (Feng et al., 2010). Therefore, such technologies can be used to measure changes in urban green spaces, vegetation health, and land use patterns, offering real-time data for evidence-based planning;
2) Data Analytics and ML: ML and Big Data analysis can serve as valuable tools that can assist in tackling issues related to data accessibility, uncertainty, and gaps in socio-ecological research within the field of ESs (Manley et al., 2022). Leveraging big data analytics and ML algorithms enables predictive modeling for ESs and urban planning, enhancing the ability to anticipate and respond to urban challenges;
3) Geospatial Analysis methods and tools: Advanced geospatial data and Geographic Information Systems (GIS) can provide critical insights into ESs distribution, assisting urban planners in decision-making for sustainable land use and resource management (Nemec & Raudsepp-Hearne, 2013).

Tab.2 provides a synthetical description for each category to introduce the main technological areas and their development useful for the design of interesting research trajectories to explore with respect to the aim of the paper. The technologies outlined in Tab.2 are partially already applied in cities. A recent EU Parliament study (Pellegrin et al., 2021) on AI and urban development has outlined the already deployed approaches for the exploitation of data and data analytics in cities, namely "Predictive Analytics (build statistical models that can classify/predict the near future) Real-Time Analytics (analyze data as it is created to provide instantaneous, actionable business intelligence to affect immediate change) Near Real-Time Analytics (analyze indexed data to provide visibility regarding current environment, provide usage reports) Historical Analytics (build data warehouses, run batch queries to predict future events, generate trend reports)" (Pellegrin et al., 2021, p. 19).

Technology Area for ES	**Description of benefits**	**Technology**
High Resolution local input data	More accurate estimates of ecosystem services at a local scale; visualization and understanding for linking ecosystem services to the local areas; more insight in the local spatial distribution of ES supply and influencing mechanisms; less biased estimates; more detailed information for ES assessment based on land use type (Van Bodegom et al., 2020).	Satellite (remote sensing) technologies
Data science for locally fit transfer functions	New (and open) datasets help in transfer functions calculation; defining value transfer functions by allowing deriving the optimal function (through machine learning); exploitation of already available machine learning technologies (ARIES tool) (Van Bodegom et al., 2020).	data-driven models using artificial intelligence (Machine Learning/AI)
Insights in trad-offs and synergies among ecosystem services	Digitalisation of (calculations of) ecosystem services facilitate overlaying the spatial occurrences of ecosystem services; identifying hotspots of ecosystem services; Information on spatial (co-)occurrences help to identify trade-offs and synergies among ecosystem services; Helps to evaluate ecosystem multifunctionality (Van Bodegom et al., 2020).	Geo-spatial analysis

Tab.2 Description of the main emerging technology areas characteristics for ES measurement

These areas of investigation appear promising in terms of potential knowledge and insights to gain for a better understanding of phenomena in cities. As an example, the urban informatics approach has emerged for exploiting data and new technologies to better understand the complexity of cities (O'Brien, 2022). It merges urban studies, social sciences, data science, and computer science for the definition of data-driven approaches able to better explain urban phenomena by examining social interactions, mobility patterns, environmental dynamics, etc. Given these abilities, it represents valuable support to inform policymakers and planners (O'Brien, 2022). This preliminary analysis of the ESs topic, its relevance for planning, and the role that KETs can play to support a data-driven perspective for planning the transition of cities highlight the relevance of the spatial dimension of ESs intended as the understanding of detailed and location-specific information about their distribution, their status, their evolution and value for cities and territories deemed relevant for the better comprehension of complex socio-ecological dynamics at the core of transformative processes. Therefore, spatially explicit information is deemed crucial for supporting local decision-making processes and stakeholders as ecosystems are heterogenous and their services vary across space and time (Van Bodegom et al., 2020).

3. The spatial dimension of Ecosystem Services

This section focuses on the analysis of spatially explicit ES assessment and accounting methods that are considered valuable in addressing the knowledge gap regarding the nexus between ESs and planning. Three interrelated analytical approaches are examined: the United Nations System of Environmental Economic Accounting – Ecosystem Accounting (SEEA EA) (United Nations, 2021); the EU Mapping Ecosystem Services (MAES) framework (EC-JRC, 2020), developed as part of the EU Biodiversity Strategy; the EU INCA Project (EC Eurostat, 2021), which serves as a synthesis of the previous approaches. These three approaches share commonalities and similarities, as their goals overlap, and, in the case of the MAES and EU INCA project, they build upon the UN SEEA-EA analytical approach. They are explored with the aim of identifying the relevance and centrality of spatially explicit data and indicators in ESs assessment and accounting and the potential of KETs for a data-driven planning of cities' transitions centered on the nexus ESs and KETs.

Such analytical frameworks have been selected given their relevance and possible implications for planning, as the information on ecosystem extent and conditions result helpful not only for their assessment but also for informing policy and decision-making in sectors that impacting or depending on ecosystems and natural resources, including land-use planning, (UN SEEA-EA, 2021).

3.1 The United Nations System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA EA)

The United Nations System of Environmental-Economic Accounting Ecosystem Accounting (SEEA EA) (UN, 2021) is a spatially explicit and integrated statistical framework designed to structure biophysical data and information about ecosystems, monitoring changes in their extent and condition, assessing ESs and potentially their assets by linking such information with measures on economic and human activities (EU Commission-JRC, 2022). The SEEA-EA framework integrates five distinct measurement perspectives relevant to the developed framework (UN, 2021): spatial perspective (ecosystems occurrence within a defined area), ecological perspective (focus on their integrity, status, health, and condition), societal benefits perspective (source of benefits for people, economy, and society), asset value perspective (assets providing services and benefits for the future depending on their status), Institutional ownership perspective (ecosystems in relation to economic and legal entities). The core units of the SEEA-EA accounts are Ecosystem Assets, which refer to spatially contiguous areas that are internally consistent regarding their ecosystem type, conditions, and ES flows (EU Commission-JRC, 2022). The recent EU report on mapping and assessing ecosystem conditions has outlined the five core accounts (see Fig.3) that characterize data on ecosystem assets in the SEEA-EA framework (EU Commission-JRC, 2022):

i) Ecosystem extent accounts that record the area for each ecosystem within an *ecosystem accounting area*. Their extent is measured over time by ecosystem type and quantifying the changes in extent from one type to another of ecosystem;
ii) Ecosystem conditions that measure the condition of ecosystem assets in terms of selected characteristics at specific points in time providing information on the health of ecosystems;
iii-iv) ESs flow accounts (physical and monetary) quantify the supply of ESs by ecosystem assets and the exploitation of those services by economic units, included households;
v) Monetary ecosystem assets accounts provide information on stocks and changes in stocks of ecosystem assets.

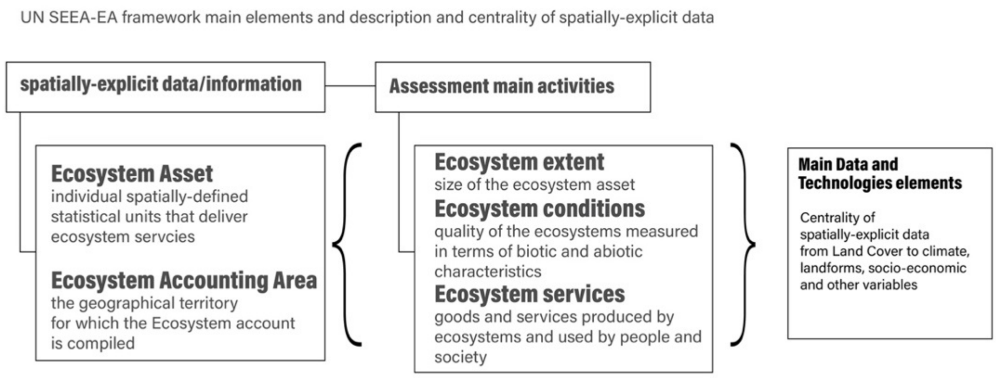


Fig.3 UN SEEA-EA framework main elements and description and centrality of spatially-explicit data

In this framework, one of the key features is the ability to integrate spatially referenced data about ecosystems, such as location, size, and condition of ecosystems in a given area, and track their changes over time (UN, 2021). Therefore, the availability of spatial data in describing ecosystems and their economic uses is deemed significant for the accounting activity, as well as the thematic and spatial detail of these data, their geospatial comparability, and integration in shared spatial data infrastructure (UN, 2021).

4.2 The EU – Mapping and Assessment of Ecosystems and their Services (MAES) work

In 2011, the EU defined a Biodiversity Strategy with the primary objective of inverting the decline of biodiversity and the services provided by ecosystems. One notable feature of this Strategy was its introduction of an ecosystem framework within the context of biodiversity policy (EC-JRC, 2020). One of the key actions outlined in the Strategy, Mapping and Assessment of Ecosystems and their Services (MAES) was expressed in Action 5 (EC-JRC, 2020). This action called upon Member States, with support from the Commission, to conduct comprehensive mapping and assessments of the condition of ecosystems and their associated services within their national territories, including the economic assessment of these services and advocating for the integration of these values into accounting and reporting systems at both the EU and national levels (EC-JRC, 2020). The main challenge for Action 5 was to increase and operationalize the currently available scientific knowledge on ecosystems and their services in the EU to support and guide policy decisions (EC, 2013).

The MAES Working Group has developed an operational framework involving policymakers and researchers (EC-JRC, 2020) and promotes a spatially explicit approach to mapping and assessing ecosystem conditions. The operational framework is characterized by four main elements (EC-JRC, 2020):

i) a conceptual frame – developed in the initial stage of the work – that connects ecosystems, biodiversity, and people, serving a conceptual basis for the design of integrated ecosystem assessment, that assumes how pressures, conditions, and services within ecosystems are interconnected;
ii) a common framework to describe the ES assessment process from mapping ecosystems to the assessment of ecosystem conditions, ES;
iii) typologies for Ecosystems, pressures, conditions, and ESs;
iv) a selection of indicators per ecosystem type to assess the pressures, conditions, and ESs.

The MAES work resulted in an agreed analytical framework that includes standards and indicators for mapping ecosystem conditions and ESs (EC-JRC, 2020). Standards include typologies for ecosystems and ESs and indicators – spatially explicit – for assessing ecosystem conditions and services per ecosystem type (EC-JRC, 2020). The conceptual model on which it is rooted assumes that the delivery of certain ESs is dependent both on the spatial accessibility of ecosystems as well as their conditions (Burkhard et al., 2018).

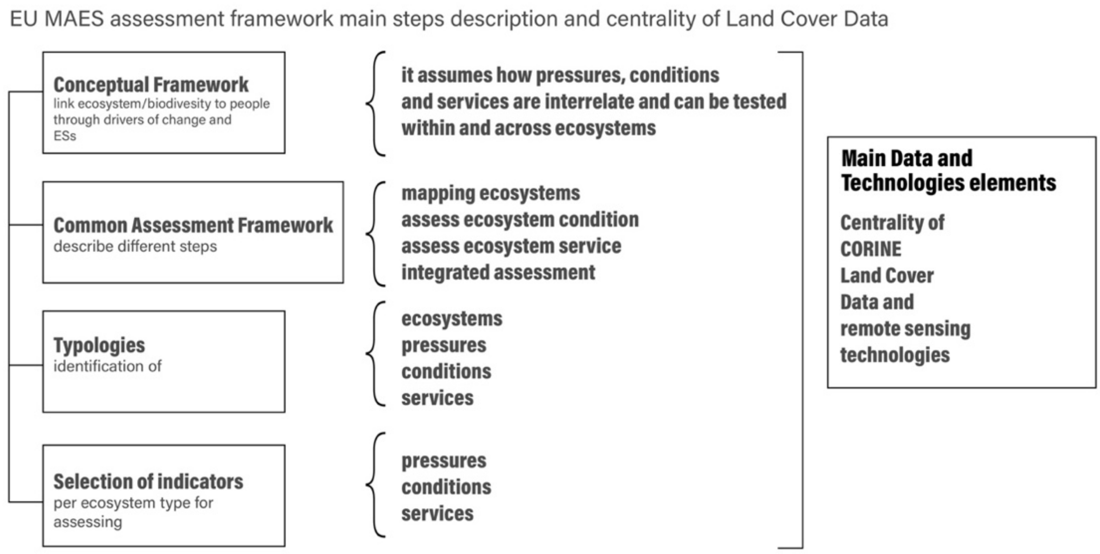


Fig.4 EU MAES assessment framework main steps description and centrality of Land Cover Data

The MAES framework is articulated in four main elements (EC-JRC, 2020) (see Fig.4):

i) a conceptual framework that establishes a linkage between ecosystems and biodiversity with people via drivers of change and ESs;

ii) a common assessment framework for describing the different steps for the ecosystem assessment, from their mapping, assessment of ecosystem condition, services and integrated assessment;
iii) identification of typologies for ecosystems, pressures, conditions, and services;
iv) a selection of indicators per ecosystem type finalized at the assessment of pressures, condition, and services.

In the MAES approach, the exploitation of data for measuring ecosystems and their extents, as well as indicators to measure their conditions, is deemed relevant (EC-JRC, 2020). Land Cover data (EU CORINE Land Cover) have been assumed as a reference dataset for delineating the extent of ecosystems, analyzing the trends in the extent of ecosystems, and have been used as an input layer for the calculation of trends for specific ecosystem condition indicators (EC-JRC, 2020). Such data and indicators should refer to the current spatial distribution of ecosystems and their use specifically for each ecosystem type, defining in this way a spatially explicit knowledge about ecosystem conditions and influencing pressures (EC-JRC, 2020). Mapping and assessment of ecosystem conditions exploit data that are available at multiple spatial scales (from site-level measurements to remote sensing and modeled data at the landscape level) (EC-JRC, 2020).

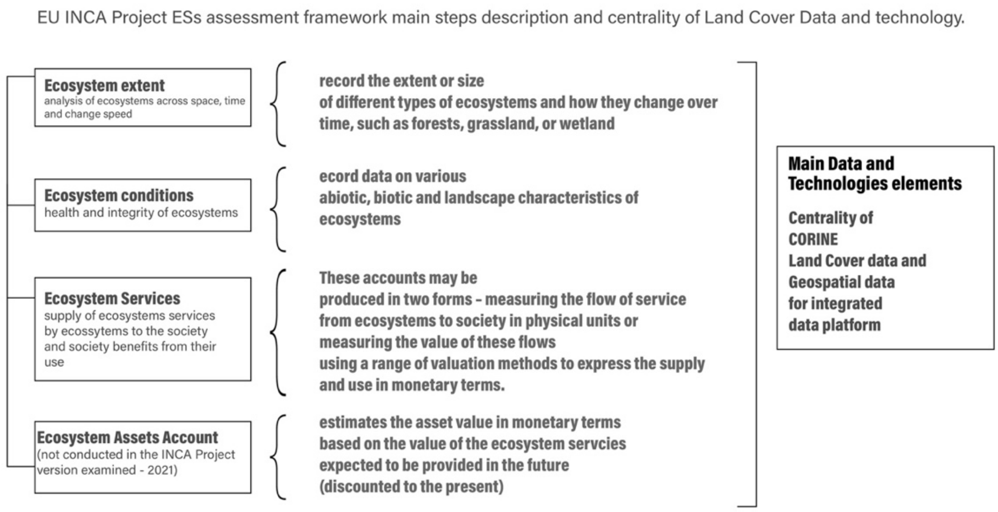


Fig.5 EU INCA Project ESs assessment framework main steps description and centrality of Land Cover Data and technology

For example, remote sensing-derived indicators are considered optimal (when available) to provide "several parameters such as land cover, which is used for calculating forest connectivity and landscape metrics, but also indices of plant physiology and stress (i.e., functional) such as NDVI or structural metrics such as tree cover density" (EC-JRC, 2022: p. 67) (see Fig.5).

4.3 The EU INCA Project

The EU INCA Project (EC Eurostat, 2021), launched in 2015, provides a bedrock in the ESs accounting and assessment by improving the spatially explicit perspective reported in the UN SEEA (UN, 2021). The approach focuses on the need for established and regular measurement of ecosystem extent, condition, change over time, and the quantity of services these ecosystems supply (EC Eurostat, 2021). The EU INCA project approach was closely linked to the MAES (EC-JRC, 2020) at the EU level and has provided inputs at the global level to the UN SEEA EEA (UN, 2021). Concerning the MAES approach, the INCA project adopted "a more rigorous and structured accounting approach to describe ecosystems, their services, and how they change over time" (EC Eurostat, 2021, 12). The INCA project has focused on the accounting for ecosystems following a threefold measurement activity, which is embedded in the SEEA framework (EC Eurostat, 2021, 11-12): i) Ecosystem extent accounts; ii) Ecosystem condition accounts; iii) ESs accounts; iv) Ecosystem Assets Account (see Fig.6).

This analytical approach grounded on spatially-explicit data and information unveils interesting potential insights on gaining knowledge on ESs.

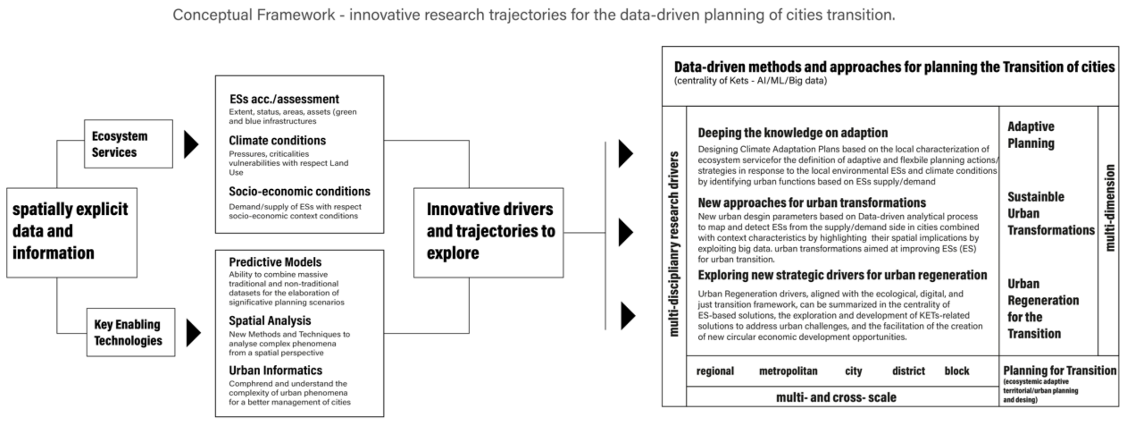


Fig.6 Research drivers and trajectories for the data-driven planning of cities transition centered on ESs and KETs

The first is related to *Ecosystem extent accounts* (1), which record the extent or size of different types of ecosystems and their change over time. The Ecosystem extent accounts are built exploiting the Corine Land Cover data (land use data) from the EU Copernicus Earth Observation Program (EC Eurostat, 2021). The Ecosystem extent account provides insight into the type, distribution, and share of different ecosystem types at the country level (or other chosen territory) by providing dimensional data (area) on the increase or decrease ('stock') of ecosystems across a country (or territory) over time and at which speed this change occurred (EC Eurostat, 2021). The spatial data on distribution of ecosystem type provide useful insights for the calculation of the accounting of ecosystem conditions and ES.

The second measure, *Ecosystem conditions accounts* (2) collects data on abiotic, biotic, and landscape characteristics of the ecosystem. Ecosystem condition is related to the ecosystem's *health* or ecological integrity, which can be measured by selecting an appropriate set of ecosystem variables (EC Eurostat, 2021). Condition accounts register information on abiotic, biotic, and landscape characteristics of ecosystems for measuring and assessing their quality. This information is important to determine the type and quantity of services that the ecosystem can provide, as the poor management/degradation conditions of ecosystems can lead to the loss in delivering multiple services (EC Eurostat, 2021). According to the analytical approach developed for the INCA Project (EC Eurostat, 2021), ecosystem conditions can be measured in two ways. The first, by selecting appropriate sets of ecosystem variables describing the changes in the condition of ecosystems changes. In this case, usually, higher values of such variables are, in most cases, associated with a higher condition of ecosystems and, thus, a higher potential to deliver multiple ES. Alternatively, the *conditions* can also be detected by measuring the pressures acting on ecosystems, such as nitrogen pollution, land conversion, invasive alien species (EC Eurostat, 2021).

The third, the *ES accounts* (3), record the supply of various ES by ecosystems to society and how the latter benefits from their use. ES are crucial for humans' well-being and the economic systems. The Ecosystem service accounts measure the flows or quantities of services that the society is using (demand). These accounts can be measured in two forms: i) measuring the flow of service from ecosystems to society in physical units; ii) measuring the value of these flows using a range of valuation methods to express the supply and use in monetary terms (EC Eurostat, 2021). The data and information derived from the ecosystem extent and conditions are inadequate to measure and assess the linkages (transactions) between ecosystems and economies. Therefore, understanding and mapping the supply and demand of ESs is an important element to consider (EC Eurostat, 2021). In the mapping and quantifying the supply and demand of ESs there could be two potential interesting insights. The first is related to detecting *unmet demand* situations in which economic and societal needs for ESs remain unsatisfied (when the ecosystem needed to provide the requested services is not present). The second is related to those situations where ESs are overexploited (used beyond their sustainability levels). However, in the accounting process, the focus is on the actual flows of ESs, which are measured through supply and use (demand) tables. The INCA project approach – for the assessment of ESs – relies on the measurement of two drivers affecting the use of ESs: the ESs potential and the ESs demand. The first is an estimate of what an ecosystem can offer in terms of services, and it is based on the limits of ES. The ES potential can be mapped by exploiting the information and data derived from the ecosystem extent account (surface area) and the ecosystem conditions account (conditions of the ecosystems) and based on other climatic and environmental data (EC Eurostat, 2021). The second, the ESs use – or demand – can be mapped and aggregated for an accounting area, and the actual use can be estimated "as the share of demand that can be satisfied by the potential" (of ESs) (EC Eurostat, 2021, 26).

The last one, the *Ecosystem Assets accounts* (4), record stocks of assets and changes in these assets. Ecosystem asset accounts estimate the value of ecosystems. The asset value in monetary terms is usually determined based on the value of the ESs expected to be provided by a particular ecosystem in the future, discounted to the present (This account was not described in the Accounts' report examined).

The EU INCA Project emphasizes the foundational relevance and importance of data and technologies for making Ecosystem accounting operational (EC Eurostat, 2021). Such a process requires the integration of different data both on ecosystems and economies (EC Eurostat, 2021) (see Fig.7). Geo-spatial data and technologies are crucial to analyze their conditions and detect their distribution (EC Eurostat, 2021). Therefore, the organization, finding, and analysis of meaningful (geo)spatial data through integrated platforms is crucial (EC Eurostat, 2021). Such elements are deemed important in terms of possible urban planning implications given the potential knowledge available on ESs – thanks also to KETs.

5. Discussion and conclusions: an innovative research perspective for a data-driven planning of cities transition centered on ESs and KETs, and its possible planning implications

The paper focused on the nexus between ESs and KETs as a potentially significant element for the future development of promising research trajectories in urban planning, we have argued the potential centrality of the linkages between ecosystem services and key enabling technologies for a better understanding of the complex dynamics and relationships occurring in cities and territories in line with the ecological and digital transition paths. Such relevance emerges from the analysis of the main adopted ecosystem services assessment methodologies, which are grounded on spatially explicit methods for their assessment and are deemed important for this contribution. This perspective places data-driven planning as one of the central elements in guiding cities and territories through their transition and opens to multidisciplinary research approaches that can shape innovative pathways to enhance cities' and territories' sustainability and resilience and generate interesting planning implications.

The need for cities to adapt to new contexts implies new evolutionary perspectives for planning, intended not as the simple direction of urban development towards predetermined urban configurations but rather for enhancing cities' capacity to adapt to their dynamic environment (Rauws & De Roo, 2016). The urgent challenges for cities and territories regarding their sustainability and resilience have heightened the necessity for a more profound understanding and more innovative methods of planning and managing urban areas (Bibri, 2021). The analytical approaches examined related to ESs have emphasized the relevance of spatially explicit and related data, information, and technologies for the analysis of ESs together with the importance of focusing on the local scale. The conceptual framework developed for this paper (see Fig.6) considers two central elements for planning the city's transition towards sustainability and resilience from a data-driven planning perspective: ESs (and their spatially explicit relevance) and KETs. Fig.6 illustrates the connection between ESs and KETs in defining new research trajectories that characterize innovative data-driven planning perspectives and identify promising research drivers to explore. The possible research drivers to explore reflect the current challenges that cities are called to face and, therefore, that planning is called to address: the development of effective climate change mitigation and adaptation measures, the need to reduce the impacts of urban changes (transformations) on natural ecosystems for improving human well-being while maintaining biodiversity, the challenge of implementing urban transition through urban planning thanks to the integrated approach intrinsic to urban regeneration. These research drivers leverage the centrality of the nexus ESs-KETs for urban planning in response to the overall aim set out by the EU in the Green, and we outline them as follows:

1) Adaptive and Regenerative Planning – for addressing urban and territorial fragmentation for climate change;
2) Sustainable Urban Transformation design – for exploring the implementation of multidisciplinary approaches for urban transformation planning and design;
3) Urban Regeneration for the transition – for exploring the development of new drivers for urban regeneration to plan cities' transitions.

Each of the potential research drivers to explore is provided consistency with the "planning" need and the technological elements that can be associated.

The first research driver focuses on deepening the knowledge of adaptation (towards adaptive planning) of cities and territories in the context of the EU priority to define a more sustainable development path by decoupling economic development from natural resources. It emphasizes the potential of data-driven approaches for designing and implementing local Climate Adaptation Plans to offer robust and relevant information based on the local characterization of ESs for tackling urban and territorial fragmentation through transformative interventions that are more consistent with local dynamics. Data integration in tradition urban planning approaches can provide useful understanding of territorial vulnerabilities, transformations generated by climate changes, and socio-demographic dynamics (Capriati & Malavolta, 2024), paving the ground for a better comprehension of socio-ecological dynamics. Local climate adaptation plans can be designed and implemented, starting with green and blue infrastructure (ESs providers) enhancement as a central element for the future development of cities. This setting implies considering multi-dimensional and multi-scalar elements that characterize local dynamics from the social, economic, and environmental dimensions. From the technological perspective, it implies collecting, analyzing, and modeling vast amounts of data to build a knowledge framework on the dynamic local environment. Combining satellite data sources with conventional data can be complemented by the potential of Artificial Intelligence through Machine Learning for developing predictive models capable of simulating short-, medium-, and long-term scenarios based on the variation of context-related variables (ESs variation/sensitivity, socio-economic factors, planning considerations, and climate dynamics).

The second research driver outlines the need for exploring new approaches in defining and designing urban transformations (sustainable urban transformation) through a data-driven analytical process for mapping and detecting ESs from the supply/demand perspective in cities, complemented by contextual characteristics that highlight their spatial implications through the utilization of big data. It could aim to define the planning and design of the restructuring processes generated by the ecological and digital transition mechanisms by defining sustainable urban transformation processes. Specifically, by capturing complexities inherent in urban environments, it would be possible to unveil patterns and relationships that can inform more effective and responsive urban planning strategies. This data-driven perspective could contribute for formulating an analytical process for shaping urban planning and governance approaches, with the aim of defining urban transformations that enhance ESs. This process can contribute to the identification of the impacts of urban transformations by assessing them from an ecosystem perspective (intended as the ability to reduce the pressures on natural ecosystems) and detect the potential leverage elements for urban transition by exploiting data from satellites, sensors, and other available sources to identify and detect ESs at the district level, facilitating the planning and design of sustainable urban transformations. Such approaches could reinforce and improve already existing perspectives, for example those related to the implementation of urban design strategies centered on Nature-Based solutions in defining urban transformations (Mazzeo & Polverino, 2023).The third research driver focuses on the exploration of new strategic drivers for urban regeneration (urban regeneration for transition) for implementing transition-oriented strategies, mechanisms, and tools more aligned with the current challenges that cities are called to face. Urban transformations, which serve as catalysts for socio-ecological and socio-technical demands for change in cities, can be planned by adapting urban regeneration strategic drivers adaptable to contextual conditions. Urban Regeneration drivers, aligned with the ecological, digital, and just transition framework, can be summarized in the centrality of ESs-based solutions, the exploration and development of KETs-related solutions to address urban challenges, and the facilitation of the creation of new circular economic development opportunities. Additionally, they could encompass the deployment of social inclusion-related processes by acting on cross-cutting elements such as public services accessibility, education, and labor policies and reducing inequalities for the most vulnerable groups. Specifically, given the EU priorities for the Green Deal, it can ensure, if properly managed, a just and inclusive transition in the definition of a more sustainable path for cities thanks to its multi-dimensional (social, economic, and environmental) nature. In this context, the recent emergence of urban informatics (O'Brien, 2022) can result in the understanding of urban dynamics (social, economic, environmental) and, consequently, implementing tailored actions and interventions adapted to the specific context needs.

Besides the implications of such a research perspective regarding knowledge advancements on the topic under investigation, a stronger inclusion of ESs in urban planning is considered central for the promotion of sustainable urban development (Cortinovis et al., 2020). Although ES-related actions and different tools for their implementation are already included in several urban plans' experiences, there are still issues to address in terms of knowledge transfer into planning practice and in usable methods for embedding effectively ESs information into planning processes (Cortinovis & Geneletti, 2018). The research drivers outlined in this section could potentially provide useful and helpful insights in this direction.

The integration of the nexus ESs-KETs into urban planning can potentially result in a more holistic, resilient, and sustainable approach to city development that considers the complex interactions between natural systems, human activities, and technological innovations. Such an approach would be characterized by a high degree of flexibility, intended here as the ability to interpret the change in local dynamics conditions and respond through adaptive strategies centered on the supply/demand of ESs. The identification of criticalities and pressures on ecosystems, through the ESs perspective, can result in the identification of urban functions that make urban areas more responsive – and less vulnerable – to climate changes and able to withstand and adapt to shocks and stresses.

The exploitation of advanced geospatial data analytics based on AI/ML/Big data for ESs assessment can reinforce this perspective, as it could enable urban planners to build a knowledge framework tailored to reducing the pressures on natural ecosystems since the initial phases of the planning processes, and it could result helpful in the elaboration of adaptive planning scenarios based on real-time information, improving the efficiency of resource allocation, infrastructure development, and land use management.

The operative implications for the planning-design process could be multiple. First, exploring these research drivers can contribute to enriching and enhancing planning practice. The potential of KETs exploitation could enhance the knowledge and interpretation, also from an evolutionary and historical perspective, of urban-territorial and landscape structures. In addition, developing KETs and associated technologies and approaches allow for speeding up the data collection and analytical processes finalized in the design of Comprehensive General Plans and implementation tools. The combination of traditional and new datasets deriving from such technologies – such as satellite and remote sensing – allows a better comprehension of the complex phenomena affecting cities and territories from the global and local levels. Second, the fast-paced growth of AI and ML techniques, together with the augmented capacity and performance of advanced calculators, could allow the process of massive amounts of data and elaborate accurate and solid predictive models, which in turn can provide valuable support for the elaboration of different planning scenarios. Third, by identifying the ESs demand and supply, thanks to their quantification through KETs, such elements could be re-framed into Zoning in terms of detailed regulations for facilitating more sustainable mixed land use, compact development, and green building practices through renovated design parameters aimed to reduce the pressures on natural ecosystems, increasing energy savings and performances, and promoting circular economy.

The urban regeneration approach could merge these potentials. Thanks to its highly adaptive strategic drivers, it could be the umbrella to facilitate the transition of cities by promoting urban transformation processes able to catalyze the context conditions on the ecological (ESs), digital (KETs), and just (socially inclusive) development drivers. Moreover, institutional and regulatory aspects could potentially support this perspective. The first implies the development of institutional activities focusing on ESs as leveraging elements for institutions in terms of organizational and management aspects, partnerships, and networking, which could influence the design of policies or policy actions already defined or in place – from the EU to the local level.

The second, on the basis of the knowledge gained on local ESs, could identify financial instruments able to valorize and optimize ESs and experimental elements (best practices, pilot projects, experimentation) that can be framed and organized for the improvement of the existing instruments. From the economic and financial perspective, providing financial incentives and subsidies to citizens, businesses, and organizations that adopt sustainable practices can support the planning of cities' transition.

We are aware of the intrinsic limitations of the depicted scenarios. However, as outlined in Fig.1 and Fig.2, the interest in this topic and its relationship with urban planning is gaining relevance, and the research drivers outlined in this contribution, together with the potential implications for planning exposed, are part of a complex and multi-faceted debate the oriented at addressing the current challenges that cities are calling to face in their transition to sustainability. Further studies could explore the research drivers outlined with a more in-depth literature examination or complement it with the analysis of urban plans for a better understanding of ESs inclusion in urban planning. Furthermore, while the paper's outlines of the main characteristics of the UN approach (UN, 2021), it pays attention exclusively to the EU perspective. Further studies can expand the investigation by including also other analytical approaches developed in other countries (United States, China, etc.).

In conclusion, as cities face the rapid pace of urbanization and its associated challenges, innovative research trajectories and drivers to explore offer possible pathways toward more sustainable, inclusive, and resilient urban futures. By embracing data-driven decision-making and planning, leveraging new technologies, fostering community engagement, and pioneering policy innovation, cities can chart a transformative course that prioritizes the well-being of their residents.

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Image Sources

Fig.1 to Fig.6: Authors' elaboration

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