Green Energy and Technology

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Smart and Sustainable Planning for Cities and Regions

Results of SSPCR 2022

Springer

Green Energy and Technology

Climate change, environmental impact and the limited natural resources urge scientific research and novel technical solutions. The monograph series Green Energy and Technology serves as a publishing platform for scientific and technological approaches to "green"—i.e. environmentally friendly and sustainable—technologies. While a focus lies on energy and power supply, it also covers "green" solutions in industrial engineering and engineering design. Green Energy and Technology addresses researchers, advanced students, technical consultants as well as decision makers in industries and politics. Hence, the level of presentation spans from instructional to highly technical.

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Foreword

As someone who has spent nearly 15 years in the energy and sustainability field, I can confidently say that it is not always easy to work in this sector. There are days when the challenges seem impossible, when it feels like the world is moving in the wrong direction and it seems like there are no good solutions in sight. However, at times like these, it is important to remember that we are living in a pivotal moment and that there is hope.

The Smart and Sustainable Planning for Cities and Regions conference organized by Eurac Research has brought together some of the brightest minds to share their experiences and insights. This resulting book is a testament to the power of collective intelligence and provides a roadmap on how we can all work together to make the world a better place.

In the face of eschatological worldviews and eco-anxiety, it can be easy to feel overwhelmed and helpless. The chapters in this book, however, provide a different perspective, one that is grounded in the idea that we can all take action to make a difference. Whether you are a decision-maker, an entrepreneur, an activist, or simply a concerned citizen, there are steps you can take to help build a more sustainable future.

At the heart of this effort is trust. We must be able to trust our leaders, our communities, our regulators, and our companies if we are to build a sustainable future together. This means promoting transparency, reliability, and accountability, and it means putting the needs of citizens at the centre of our policies and economic models.

Of course, there is no one-size-fits-all solution to these challenges. We all come from different backgrounds and we all have our unique perspectives and circumstances. However, by working together and taking a holistic, intersectional approach, we can build a future that works for everyone.

This book is an essential resource for anyone who cares about the future of our planet. It brings together the voices of authors from different contexts and perspectives, offering a rich and diverse set of solutions to the challenges we face as humanity.

At the end of the day, we all have a role to play in building a more sustainable future. It starts with listening to each other, educating ourselves and others, and thinking outside the box. By doing our part and working together, we can build a just transition that benefits everyone. I hope this book inspires you to join the effort and share your solutions to make the world a better place.

Marine Cornelis
Next Energy Consumer
Turin, Italy

Urban Innovation: What are We Talking About? Highlights on SSPCR 2022

Who would have thought that we would once again be able to have another SSPCR conference in person? For some of us, the previous edition, held in Bolzano in December 2019, was the last group event we were able to attend. Shortly after, the COVID-19 health crisis hit and changed our world. No more trips to workshops and conferences in faraway countries, no more passionate discussions started in the hall and continued during the coffee break and no more handshakes and exchanges of business cards. For a while, it seemed like the new world was all about webinars, virtual events, conference calls, and file sharing via the cloud. Some months felt like years, and some years felt like decades. When we started thinking about whether it would be possible to do the fourth edition of Smart and Sustainable Planning for Cities and Regions, it seemed really risky. It was fall 2022, the contagion curve was starting to rise again after the summer break, and there was general scepticism. However, we did not give up, because there were many colleagues, researchers, practitioners, and stakeholders who were asking us for news and who were curious about when it would be possible to return to Bolzano. We finally succeeded. For some, SSPCR 2019 had been the last scientific conference they attended in person, for others, SSPCR 2022 was the first event they were able to travel to after the lockdown ended, and for a minority both even! More than 200 participants from 22 different nations gathered on 19–22 July to discuss urban strategies, ecological and digital transition, positive energy districts and energy communities, the future of mobility, city–territory relations, nature-based solutions, social innovation, multi-level governance, spatial data analysis and innovative business models, and much more.

Poster and oral presentations, as well as special events promoted by international projects and institutions, focused on seven thematic tracks, namely:

1. Will the climate-neutral city please stand up?
2. The hidden potential: untapping the benefits of urban transformations
3. Tackling what remains to be done: environmental sustainability in cities and regions
4. Strengthening democracy in the energy transition

5. Leave no place behind: policymaking for smart and sustainable regions
6. Planning for ever-changing mobility: mind the gap!
7. Discovering the internet of cities: from data to knowledge

This book offers a selection of 10 international contributions on the most relevant topics addressed on the different themes and illustrates of the richness of the issues discussed and the breadth of the emerging themes.

- Haase and Thaleia observe that the current renovation rate of existing buildings in the EU is only about 1–2% and investigate current business model practices in an attempt to promote cost-effective building renovation at district level and to integrate it into Energy Master Planning for cities and regions.
- Bisello, Bottero, Volpatti, and Binda also recognize the relevance of innovative urban projects aimed at promoting the urban energy transition. However, they stress the need to move from an economic evaluation of Positive Energy Districts towards an integrated sustainability assessment by using Multi-Criteria Decision Analysis supported by a Geographical Information System.
- Haase and Baer continue the debate on the sustainability assessment of Positive Energy Districts by relating it to the concept of planetary boundaries. To do that they refer to two different approaches (one from Switzerland and the other from Norway) and look to related Key Performance Indicators.
- Bastos and Rosado present a Material Flow Accounting model of the Autonomous Province of Trento (Trentino) in northern Italy, and its capital city, which is of great relevance in informing decision-makers in terms of designing for sustainable planning on a territorial or urban scale.
- Bolognesi focuses on an extremely topical subject: how energy communities can support the clean energy transition of territories without compromising historical and landscape values while enhancing local heritage, energy resources and social returns.
- Corti and Nava tackle the hot topic of optimizing last-mile logistics and the electrification of logistics fleet services as an effective way to reduce the impact of freight transport on air quality in cities. This is done by interviewing experts in this field and discussing the pros and cons from an economic, governance, and social perspective.
- Accordino, Pappalardo, Codato, Peroni, and De Marchi by combining Multi-Criteria Decision Analysis and spatial data emphasize the capability of urban railway stations to define centralities and poles of attraction, thus in turn redefine centre/periphery relationships and potentially contribute to reducing social imbalances.
- Ravazzoli investigates urban tensions and social trends by suggesting a new framework for socio-spatial analysis of actions taken by individuals, groups, or networks of stakeholders when reclaiming streets and neglected spaces (so-called communing practices).
- Sepe also reflects on how new technologies, ICT tools, and accurate design are of paramount importance in determining the suitability of both indoor and outdoor public spaces to foster social relationships and facilitate innovation.

- Mahmoud, Morello, Bisello, and Kolokotsa conclude this overview on innovative approaches to urban planning and public space design by intercepting the emerging trend of so-called augmented nature-based solutions, where the green urbanism approaches takes advantage of the latest technologies and sensors to deliver healthier and more appealing cities.

Once again, special thanks go not only to the authors who contributed to this book but also to the anonymous reviewers who undertook to go through the submitted manuscripts and provide insights and useful comments that enhanced the overall quality of the research work and readability. Our sincere gratitude also goes to the organizing committee, the organizers of special sessions and events, the colleagues who donated their time, and finally to all the participants who contributed with their attendance, questions, and interest to make SSPCR 2022 memorable.

Bolzano, Italy Adriano Bisello
Bozen, Italy Daniele Vettorato

About This Book

What can planning do across Europe and beyond to lead the ecological and energy transition and to make cities and regions more sustainable in a smart way? This book offers a selection of research and case studies on smart and sustainable planning in practice, featuring models and results from academics, policymakers, consultants, and other professionals. The chapters are drawn from the top contributions presented at the fourth international conference "Smart and Sustainable Planning for Cities and Regions 2022", held in July 2022 in Bolzano, Italy.

Despite ongoing urbanization and polarization processes, a new symbiosis between urban and rural areas emerges, linking development opportunities to intrinsic cultural, natural, and man-made landscape values. In this context, innovative planning and design projects play a fundamental role in addressing societal challenges. Moreover, the increasing availability of a wealth of big, real-time urban data and advanced ICT enables a much more frequent assessment, continuous monitoring of performance, and fine-tuning, not only of individual projects but also of whole territories and cities. In this context, (big) urban data and ICT can be of enormous help in facilitating engagement by raising awareness through sharing and visualization of data, and by providing insight into the local consequences of specific plans. Indeed, to achieve better integration of climate-energy planning, collaborative action with key stakeholders through co-design and co-creation in open innovation processes are fundamental, allowing the creation of new value propositions and encouraging a high level of trust and transparency.

The aim of the book is thus to provide a grounded and multi-disciplinary outlook, to orientate the reader in the giant galaxy of smart and sustainable planning, to support the transposition of research into practice, to scale up visionary approaches, and to design ground-breaking planning policies and tools.

Highlights

- The book offers empirical and theoretical insights into planning for smart and sustainable cities and regions.
- It combines multidisciplinary approaches, giving new solutions and ideas to both researchers and policymakers to support real-world decision-making processes.
- The contributions provide a grounded perspective on contemporary challenges to smartness, the circular economy, climate neutrality, and overall sustainability through a wealth of local and regional case studies from Europe and beyond.
- An excellent overview of up-to-date tools, models, and methods for implementing and scaling up smart city solutions and improving decision-making is provided in the research presented in the book.

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About the Editors

Adriano Bisello is an urban planner and has a Ph.D. in real estate economics. At Eurac Research, in Bolzano (Italy), he coordinates the research team on "Planning methods and evaluation of multiple benefits of the energy transition" and works as a project manager. Adriano's activities range from local to European-funded projects related to smart city governance, positive energy districts, innovative nature-based and digital solutions, and sustainable energy communities. In 2022, he was appointed Vice President of ASSURB (Italian Association of Spatial Planners) and a delegate to the ECTP-CEU (European Council of Spatial Planners—Conseil Européen des Urbanistes).

Daniele Vettorato graduated in Urban, Regional, and Environmental Planning and later earned a Masters (M.Phil.) in Urban and Regional Planning for Developing Countries. He has a Ph.D. in Environmental Engineering. Daniele coordinates the Urban and Regional Energy Systems research group at Eurac Research, in Bolzano (Italy). He has been the Vice President of ISOCARP (International Society of City and Regional Planners) since 2017. He has worked in Brazil, Chile, Cambodia, Kenya, Mozambique, UAE, Russia, and China. He is currently serving the International Energy Agency as an expert in Task 51 and Annex 83.

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Dionysia Kolokotsa is a professor of Energy Resources Management at the School of Chemical and Environmental Engineering at the Technical University of Crete (Greece). Her research has led to the advancement of energy efficiency in the built environment with the development of knowledge in the following fields: (a) integrated energy management systems, (b) the advancement of zero energy buildings and communities, (c) urban heat island deterioration and the integration of nature-based solutions and cool materials. She has coordinated numerous international research projects, and she is the Editor in Chief of Solar Energy Advances, Elsevier, and Subject Editor of Scientific Reports, Nature and PLOS Climate.

Current Business Model Practices in Energy Master Planning for Regions, Cities and Districts

Matthias Haase and Thaleia Konstantinou

Abstract Roughly 97% of the European Union (EU) building stock is not considered energy efficient, and 75–85% of it will still be in use in 2050 (Artola et al., Boosting building renovation: What potential and value for Europe? 2016). Residential buildings account for around two thirds of final energy consumption in European buildings. The rate at which new buildings either replace the old stock or expand the total stock is about 1% per year. Similarly, the current renovation rate of existing buildings in the EU is about 1–2% of the building stock renovated each year. Renovation strategies on building levels need to be derived from a combination of energy efficiency upgrades to buildings and the use of renewable energy to decarbonize the energy supply, on a district or city scale. IEA EBC Annex 75 subtask D2 focuses on promoting cost-effective building renovation at district level combining energy efficiency and renewable energy systems, by focusing on the business models that can make implementation possible. This paper intends to provide an overview of the business model archetypes that can support the development of district demand and/or supply of energy-efficient building renovations and/or renewable energy solutions by targeting various types of stakeholders. It builds upon existing literature to gain insights into the current distributed energy business model landscape. Further, implementation strategies are identified that focus on a holistic evaluation of the expected energy and CO_2 performance of the site and optimized infrastructure investment pathways.

Keywords Business models · Decarbonization · District scale

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1 Introduction

Renovation strategies on the building level need to be derived from a combination of energy efficiency upgrades to buildings and the use of renewable energy to decarbonize the energy supply, on a district or city scale. To this end, international work was coordinated under the IEA EBC technology platform in Annex75 (IEA Annex 75 2017). The work conducted in the IEA EBC Annex 75 sets out to define a methodology to identify which strategies are most energy-saving and cost-effective when applying both energy efficiency and renewable energy measures (IEA Annex 75 2017). By combining energy efficiency and renewable energy sources, the approach addresses both energy supply and demand in the built environment. In this sense, building retrofitting is an appropriate strategy to reduce demand, while the use of renewable energy aims to decarbonize the energy supply system.

Nevertheless, to apply large-scale renovation strategies and achieve the projected building stock decarbonization, identifying technical solutions is not enough. The renovation rate in Europe remains well below the targeted annual 3% (Artola et al. 2016). Some of the main barriers to renovation have to do with renovation costs and access to finance, as well as complexity, awareness, stakeholder management and fragmentation of the supply chain (BPIE 2011). As a result, business models are relevant to the implementation and acceleration of renovations. Seddon et al. (2004) define a "business model" as the outline of essential details of a firm's value proposition for its various stakeholders, and the activity system the firm uses to create and deliver this value proposition. In other words, a business model is the abstraction of a strategy, focused on the system of activities through which a firm creates economic value [4].

Given the limitations due to available financial resources and the large number of investments needed to transform a city's energy use in buildings, identifying cost-effective strategies and policies is important to accelerate the necessary transition towards low-emission and low-energy districts. Business models are thus relevant to the implementation and acceleration of renovations. A business model also provides a tool to overcome barriers such as split incentives and financial complications in upscaling renovations and combining energy renovation and energy supply. To this end, this paper aims to provide an overview of current business model (BMs) practices both for renovation and energy supply, by organising them into archetypes. Based on this analysis, the study offers an outlook on the characteristics and aspects of BMs that should be considered to combine the BM for renovation and energy supply.

2 Business Models for the Renovation of Buildings and Districts

Business model (BM) archetypes for building renovation are characterized by the way the renovation is managed, the role of the beneficiary/building owner, the involvement of intermediaries and project managers, and the return on renovation savings. This study compiled a catalogue of business models for energy-efficiency renovation by identifying four archetypes that summarize current approaches. The information was gathered by reviewing current literature and is illustrated by examples found in renovation practices and European research projects such as in (Brown 2018; Burger and Luke 2017; Gouldson et al. 2015; Haavik et al. 2014; Karine Laffont-Eloire et al. 2019; Mlecnik et al. 2019; Moschetti and Brattebø 2016; Teece 2010). Table 1 summarizes the characteristics of each archetype, highlighting the barriers they pose to upscaling to district, as well as the opportunities to overcome those barriers.

As in any general classification, there are variants to all the business models so the conceptual separation line from one to another might at times be difficult to define. For example, One-Stop-Shops can also extend their services from construction to post-construction monitoring if requested or can sub-contract the consultancy phase to a trusted company. Moreover, the simplification required to define archetypes needs to be taken into account. However, the archetypes distinctly highlight the difference in the process organization and integration of the solutions and financing.

Energy Performance Contracts (EPC) offered through energy service companies (ESCOs) provide an emerging financing mechanism, which empowers each citizen to shape their own energy efficient home through long term loans tied to energy savings. With the involvement of central or local governments, or even unusual sources like pension funds or healthcare providers, these loans can be made more affordable and attractive. This will help tilt the scales with undecided citizens to start a building energy retrofit.

Despite the advantage of EPC business models for renovations, particularly with regards to reduced or eliminated upfront costs to users, there are challenges that need to be considered (Bertoldi et al. 2021), which are hindering application of the model for housing renovation. The main challenges include performance risk, the high fees charged by ESCOs, and long-contract and old ownership structures (over 20 years, whereas many may be reluctant to sign a contract over 10 years).

For example:

- Long-contract and old ownership structures (over 20 years, whereas many may be reluctant to sign a contract over 10 years).
- Trust, where prices and revenue flows are not transparent.
- Company large initial investment (financing costs).
- Collective contract management.
- Expensive civil work.
- Individualization of systems as a freedom for families.

Table 1 Summary of business model archetypes for building energy retrofits

BM archetype	Value proposition	Financing mechanism	Barriers	Opportunities to overcome barriers
Atomized market	Single measure. Emphasis on energy cost savings	Homeowner pays for entire cost structure, payback through energy savings Access to finance through debt	Relies on individual funding and initiative Fragmented and uncoordinated problem-solving	Awareness raising Financial incentives for renovation
Market intermediation	Single measure. Emphasis on energy cost savings. Expert advice and reduced time investment for homeowner	Homeowner pays for entire cost structure, payback through energy savings Access to finance through debt	Relies on individual funding and initiative Additional interface can add to cost and time Fewer opportunities for innovation and integrated solutions	Awareness raising Financial incentives for renovation Intermediary builds trusted relationships with suppliers, to provide integrated solutions Addresses market fragmentation
One-stop-shop	Multiple measures. Emphasis on energy cost savings, comfort and environmental performance	Homeowner pays for entire cost structure, through own debt Payback through energy savings, potential extra revenue from the sale of self-generated energy One-stop-shop interface is also adequate for equity financing	Lack of awareness for the benefits of integrated services High investment costs due to complex and expensive solutions, and expert consultations	Awareness raising and coordinated renovation projects Development of integrated, modular, scalable solutions Addresses market fragmentation
ESCO (Energy Service Company)	Multiple measures. Emphasis on energy services, cost savings, comfort and environmental performance	Organizations pay upfront (lenders), charges homeowner with monthly instalments, capture energy savings and potential extra revenue from the sale of self-generated energy	Complex financial structure Long-term loans tied to energy savings	Financially attractive for homeowners Addresses market fragmentation Enables long-term planning

3 Business Models for Energy Supply

Energy supply for buildings relates to the supply of both electric and thermal energy. This section investigates business model archetypes for both the district thermal energy and electricity market. The aim is to identify current practices in business models as well as synergies within business models of energy supply companies, as they are seen in the literature.

There is a large variety of business models for energy supply. Those business models are characterized by different parameters such as the degree of servitization, meaning the range of energy services from basic to more advanced services such as energy management, project design, implementation, maintenance, evaluation and energy and equipment supply, savings guarantees, etc. Other parameters are the financing and ownership structure, the customer role, the decentralization level and the infrastructure it refers to. Four kinds of approaches of business models were identified:

1. Demand response (DR) and energy management systems (EMS).
2. Electrical and thermal storage (ETS).
3. Solar PV businesses (PV).
4. Customer relations and services (CRS).

There were basically six different business model archetypes identified, which can be split into several types and even sub-types. Sub-categories within the three main approaches can be defined as BM archetypes. Table 2 summarizes the types of business models and details their characteristics.

Six distinct themes that outline the value creation drivers for energy supply business models (BMs) were identified as follows:

- District heating BMs are often supported by local authorities due to the large infrastructure that needs to be installed. New generations of DH networks try to lower operating temperatures to increase efficiency and collect waste heat (e.g., from other sources).
- Going Green BMs are the ones where new ways of performing economic transactions have been adopted. Accounting for the content element, fossil fuel energy is replaced in these BMs with renewable energy sources, thus they are mostly technology driven BMs, nowadays with a strong predominance for solar PV businesses, (resulting in a pattern category named “Going Green”).
- “Building energy communities” is another pattern category where new organizations based on co-participation form are addressed in the structure element, while the governance element is based on shared resources and governance.
- Lock-in-centred business models refer to the ability of firms to attract, maintain and improve customer and partner associations with the BM.
- Complementarities-centred BMs refer to BMs as having goods bundled together instead of providing each of the goods separately.
- Efficiency-oriented energy BMs are the ones where measures are taken to achieve increased transaction efficiencies.

Table 2 Summary of business model archetypes for energy supply

BM archetype	Approaches explored	Value proposition	Financing mechanism	Barriers	Opportunities to overcome barriers
District heating BM	ETS, CRS	Economies of scale, exploiting various heat sources (including waste heat)	Incomprehensive tariff structure, usually high connection costs, obligations to connect to existing networks	High investment costs Too high temperatures to utilize low-temperature (waste) heat Low heat energy costs (not reflecting external costs)	New generation of DH with low circulation temperatures Incentives from policymakers Including external costs (CO_2 tax) EPP including other sectors Heat storage opportunities
Going Green models	PV, ETS	Renewable electricity generation from various stakeholders	Energy utilities use renewable energy and extend their value proposition by adding on new renewable energy sources to satisfy customer demand for renewable energy	High investment costs, limited local renewable energy potential, mismatch between demand and supply	Lower operational costs (reflected in Lifecycle costing (LCC)), energy storage
Building energy Communities BMs	PV, ETS	Renewable electricity generated by private investors in a community form	Allows multiple participants to invest in and/or benefit directly from the energy produced from a shared system	Legal restrictions, lack of expert knowledge	Adjusted legal framework (sand pitch), "One-stop-shop" offers

(continued)

Table 2 (continued)

BM archetype	Approaches explored	Value proposition	Financing mechanism	Barriers	Opportunities to overcome barriers
Lock-in oriented business models	CRS	Offer energy functionalities, e.g., provide energy services that reduce energy consumption using more efficient energy systems	Customers pay a fixed price per kWh for direct use of the solar system, immediate reduction in operating costs, a predictable cost of electricity over 20 years and lower investment costs	Based on existing relationships with customers of local authorities, so difficult to attract new customers A more energy-efficient system is fossil fuel based	Obligations Combine Renewable Energy Supply (RES) and energy efficiency (EE)
Complementarities-oriented energy supply business models	DR, ETS	Active grid management of energy (balancing the demand–supply mismatch)	Revenues from actively managing the grid	Costs for grid balancing services are not established Various stakeholders for grid management (consumers, producers, Distribution system operators (DSO), Transmission system operators (TSO)	Establish incentives for grid stability services (IEA EBC Annex82) Add time to the value of energy (summer vs. winter) Convert energy supply to energy-balanced services (incl. storage)
Efficiency-oriented energy business models	CRS, ETS	Economies of scale	Cheaper production through economies of scale, digital services for distribution and sales	Scaling up mechanisms Infancy of digital technologies Slow (and too big?) established market players (with little incentives for change)	Opportunities for new market participants Active change management

4 Combining Business Models

District heating work is not generally part of the renovation business model. Some measures on a building level that comply with district heating, such as low-temperature radiators, are included in building energy efficiency renovation packages. Thus, this creates two almost parallel, business models, one at a household and business level, and the other at a higher system level, where digital platforms aggregate multiple vectors and services on a large grid scale. These two BMs need to be connected in a way where real (also digital) innovation of these business models is combined with renovation BMs. These two BMs ought to be brought together through technical and market means—aggregation and market trading. For example, innovation includes exploring the role of energy aggregators in managing the energy consumption of specific groups of users; creating a system focused on local energy and economic needs and investing in the built environment to create local value through retrofits or solar PV. This will also help to create and capture social and environmental values, especially for users, through digital innovations.

Local energy markets (as shown in the Community Energy BM) are seen as the most suitable to also integrate renovation-based BMs. Thus, the local demand and supply system can be optimized. Local authorities can help to set up these clusters and build a framework for establishing innovation clusters where all stakeholders are represented and where intermediaries (e.g., expert companies) collaborate with beneficiaries on the common goal of decarbonizing the built environment. For a successful implementation, it is essential to start with an energy master plan that includes local constraint analysis, political goal setting and setting up alternative solutions.

Typically, energy communities follow the Energy master plan approach by:

- allowing for total life-cycle costs to be minimized, supporting the decarbonization of the energy supply process to end users and increasing the resilience of thermal and power energy supply systems.
- implementing novel and more efficient end-use technologies, Building Energy Management Systems and energy supply solutions, including thermal energy storage, combined heat and power (CHP) plants and reversible heat pumps. Integrating renewable energy sources into distribution grids can help to slow down or even reverse the increase in energy demand, reduce the size of energy generation equipment by shaving peak loads (in particular cooling peaks in warm climates), and make energy systems more resilient to the growing number of different natural and manmade threats and hazards.
- integrated energy systems which act as so-called “virtual batteries”. District heating can be provided by a CHP plant, heat pumps, electric boilers, and thermal energy storage (TES) units. These measures allow for scheduling of equipment operations in response to daily and weekly fluctuations in prices on the electricity market.
- the use of modern state-of-the-art district hot water systems which reduce operating costs; increase overall system efficiency; integrate the use of waste heat

from industry and renewable energy sources, both directly and via heat pumps; and generally improve system resilience (Sharp et al. 2020).

- building configurations that include such improvements as well-insulated building envelopes; efficient Heating, Ventilating, and Air-Conditioning (HVAC) systems with large surface radiant heating and cooling technologies (e.g., floor or ceiling mounted heating and cooling); the use of building core activation that can exploit smaller temperature differences between supply and return water used for heating and cooling, all support the use of district systems with low exergy sources, e.g., ground (geothermal), solar thermal and groundwater, river or lake water, heat from sewer systems, etc. (see also Annex 73, Guidelines for Energy Master Planning).
- sharing in these "energy communities" often a single owner is regulated to form a legal entity with one single point of contact (and decision maker) which allows energy efficiency measures to be made for individual buildings (e.g., building envelope renovation, replacing HVAC equipment and lighting systems with more efficient ones) can be used to reduce community-wide peak demand. When such projects are planned as a part of a holistic Energy Master Plan, they can improve the cost-effectiveness of the plan by improving building environmental conditions, use resources better and enhance system resilience. This approach requires collaboration between all stakeholders and strategic timing of different projects. Local communities with numerous building owners face difficulties with optimally timing building renovations for all community buildings.
- Energy communities have the potential to act as separate Microgrids. In that way they can be used to avoid distribution tariffs since the costs of operating their own low-voltage grid are lower than the distribution tariffs from the utility company. In such cases, even large gas-driven CHP plants located within the community are not connected to the community grid but are rather connected to the utility grid and operated based on market energy prices.

5 Discussion

After looking separately at energy renovation and energy supply business model archetypes, this discussion aims to evaluate the potential to combine building renovation and energy supply business models. For that, we identified stakeholder mapping, the identification of value creation, the combination of customer segments and the main drivers as the key aspects that can contribute to the development of integral business models.

5.1 Stakeholder Mapping

The nature of business model innovations involves broader sets of stakeholders working together, often in newly formed partnerships. Thus, developing a successful value proposition for users is difficult as there are multiple and sometimes conflicting end-user values, system needs and supplier/financier needs. Since these business model innovations create new interfaces between users and the grid they also open up opportunities to create new sources of value, such as reducing pressure on electricity networks, price arbitrage, time-shifting consumption etc., but these can be small or intangible. There are often trade-offs between sources of value and how that value is shared. For example, local balancing has the potential to reduce supplier imbalance costs and reduce customer bills, provide an uplift to the generator and increase supplier margins. The key challenges to developing successful business model propositions are balancing innovation, attractiveness, risk, adhering to regulations and meeting decarbonization goals. Many of these business models rely on growing local demand for RES, flexibility and storage services and see the development of value propositions as a step process, first focusing on value propositions which would appeal to a greater group of users, to then develop more innovative services that could be delivered at a later date. When trying to establish new BMs for renovation and energy supply on a district scale, clusters of stakeholders are needed and an innovation eco-system. The traditional view of such ecosystems is that it is a collection of companies situated with some level of proximity, allowing for more collaboration, interaction, development of stronger ties and a natural growth of collaborative strengths within the cluster.

5.2 Value Creation

The market becomes more personalized. Consumer behaviour, attitudes, tastes and needs are critical factors for BMs operating in decentralized systems where multiple roles for consumers are possible:

- active producers and consumers who produce and self-consume green electricity and/or heat;
- customers as financial investors in renewables;
- service users demanding light, heat, etc. instead of an energy commodity;
- local beneficiaries, project supporters/protestors/activists;
- technology hosts.

Decarbonization, digitalization and decentralization are interconnected processes and can significantly enhance the diffusion of low-carbon technologies and the ability of certain stakeholders (such as local authorities) to participate and develop innovative business models on multiple scales (from household to system level). For example, the distributed energy resource (DER) market has seen a significant increase over the past decade with increasing focus on integrating DER by both connecting and utilizing their flexibility, which has been made possible through increased digitalization in the energy system. Decentralization, digitalization and decarbonization of energy services are leading to several value creations including opening up the electricity grid, expanding (the type of) energy services; and role changes involving redefining the role of consumers and the introduction of new roles (such as aggregators and prosumers). Opening up the electricity grid takes many forms, from opening up the low voltage part of the grid to local community energy groups, to Distribution Network Operators providing forecasts of their flexibility needs in different areas 5–8 years ahead. Here, a reduction in energy demand through deep energy renovation can provide new values that energy supply-focused service companies still have to adapt to. Often, the main value propositions are improved comfort, energy use reduction and a reduction in environmental impact. Additional value propositions were related to the improvement of overall living quality and the quality of the district (Rose et al. 2021).

5.3 Combined Customer Segments

This provides possibilities for a combination of energy efficiency (renovation on a building level) and energy supply (decarbonization and exploitation of local RES) by market players that cover all aspects of this ecosystem. This combination of customer segments requires a set of market players that organize themselves in clusters to enhance resource and information flow. This provides the potential for upscaling and replication in districts and energy communities.

Innovation clusters act as ecosystems that create an active flow of information and resources for ideas to transform into reality. Through these ecosystems, a process is started by which more innovators and entrepreneurs can develop and launch solutions to solve real-world problems faster. This process creates expertise in new areas, helps to diversify the economy and allows businesses to meet their customers where they are. Additionally, an innovation ecosystem provides the means to create economic stability and resource sharing (Verdú and Tierno 2019).

The value of an innovation ecosystem lies in access to resources and the flow of information for ecosystem stakeholders. This information flow creates more investment opportunities for the right institutions to connect with the right ideas for their businesses and portfolios, at the right time, for the right reasons. Clusters (or cluster organizations) can be purposefully built and developed. The role of governments is significant, either indirectly through taxation and industrial policies or directly through national cluster programs and direct funding schemes.

In this view, pre-existing clustering of member companies matters, but there is also a belief that clusters can grow and develop over time, often developing from small, emerging clusters into globally oriented innovation superclusters. For innovation clusters in the building sector, it is important to understand the different business models in the renovation market and energy supply business.

5.4 Main Drivers

Renovation of individual residential buildings is nowadays subjected to the (compulsory) deployment of renewable energy technologies, meaning that all renovation processes result in an increase in the DER. However, this is not always the case for deployments of DER in buildings that are not yet up for renovation.

Energy poverty is central in many political agendas and thus this must be addressed in the energy master planning process. Energy renovation BMs often involve the use of established interfaces and work with incumbent players (i.e., the interface on the micro-grid remains the existing energy supplier). In some instances, these business models can exist entirely separately from the energy system and cover a diverse set of activities, such as energy generation and its onsite use by individual households.

Often these business models are put in place to deliver specific social values such as alleviating fuel poverty and providing better energy comfort. For example, a microgrid local supply business model involved social housing owned and operated by a LA, providing a certain amount of free solar power to vulnerable residents. Business models at this level are usually built on the use of specific technology and are focused on delivering benefits to users and generators. Often, part of the investment comes from public money, either as direct financing or in the form of subsidies to homeowners or other frameworks.

6 Conclusions

Within the framework of IEA EBC Annex 75, which investigates cost-effective strategies to reduce greenhouse gas emissions and energy use in buildings in cities at district level, combining both energy efficiency measures and renewable energy measures, this study presented business model archetypes for renovation and energy supply. The objective was to provide guidance to policymakers and the industry to upscale building renovations and implement renewable energy sources.

The analysis showed that there are different BMs currently in practice. They differ with regard to the degree of "servicization (energy as a service)" process organization and the role of the different stakeholders. There are no specific business models for energy supply applied to the renovation of districts.

Based on these conclusions, we propose to set up (or use existing) innovation clusters, based on these promising BMs to ensure that innovative business environments (innovation clusters) will grow that have the potential to upscale and replicate District Decarbonization Solutions in Energy communities. However, uncertainties on supportive measures for the application of DER make it difficult to develop new business models for utilities. Moreover, innovative business models need to provide additional value propositions beyond energy efficiency, e.g., related to improving the overall living quality and quality of the district, and supporting users by providing a single point of reference, like in the case of one-stop-shops.

As final remarks on business models and financing, we can highlight the role of public bodies, such as regional bodies, municipalities and their affiliated housing associations, in decision-making and financing larger (infrastructure) projects. The role of public figures is also important to support and kick-start the process, even if they do not own the business model. They should provide guarantees to build trust and subsidies to alleviate investment costs.

Moreover, the need for comprehensive energy master planning approaches for district-scale renovation became obvious, not only in implementing technical solutions but also in terms of business and financing models, as well as with regard to process management.

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References

Artola I, Rademaekers K, Williams R, Yearwood J (2016) Boosting building renovation: What potential and value for Europe? http://trinomics.eu/project/building-renovation/renovationrate

Bertoldi P, Economidou M, Palermo V, Boza-Kiss B, Todeschi V (2021) How to finance energy renovation of residential buildings: review of current and emerging financing instruments in the EU. WIREs Energy Environ 10(1):e384. https://doi.org/10.1002/wene.384

BPIE (2011) Europe's buildings under the microscope. Building performance institute Europe. http://www.bpie.eu/eu_buildings_under_microscope.html

Brown D (2018) Business models for residential retrofit in the UK: a critical assessment of five key archetypes. Energ Effi 11(6):1497–1517. https://doi.org/10.1007/s12053-018-9629-5.Businessmodel,Annex75

Burger SP, Luke M (2017) Business models for distributed energy resources: a review and empirical analysis. Energy Policy 109:230–248. https://doi.org/10.1016/j.enpol.2017.07.007

Gouldson A, Kerr N, Millward-Hopkins J, Freeman MC, Topi C, Sullivan R (2015) Innovative financing models for low carbon transitions: exploring the case for revolving funds for domestic energy efficiency programmes. Energy Policy 86:739–748. https://doi.org/10.1016/j.enpol.2015.08.012. Annex 75 business plan

Haavik T, Helgesen PJ, Svensson A, Groenhout N, Arroyo D, Costanzo E, Mach T, Dankl C, Lang G, Rose J, Thomsen KE, Hilderson W (2014) Upgrading of the non-residential building stock towards nZEB standard: recommendations to authorities and construction industry. http://task47.iea-shc.org/Data/Sites/1/publications/Task47-SubtaskB-Summary-Report.pdf

IEA Annex 75 (2017) Cost-effective building renovation at district level combining energy efficiency & renewables. Retrieved 10/10 from http://annex75.iea-ebc.org/about

Laffont-Eloire K, Peraudeau N, Petit S, Bourdeau M, Joumni H, Belaid F, Grasset H, Marchi F, Dall'oro L, Pratlong M, La XW (2019) Stunning final report: sustainable business models for the deep renovation of buildings. https://renovation-hub.eu/wp-content/uploads/2019/09/STUNNING%20Final%20Publication.pdf

Mlecnik E, Straub A, Haavik T (2019) Collaborative business model development for home energy renovations. Energ Effi 12(1):123–138. https://doi.org/10.1007/s12053-018-9663-3

Moschetti R, Brattebø H (2016) Sustainable business models for deep energy retrofitting of buildings: state-of-the-art and methodological approach. Energy Proc 96:435–445. https://doi.org/10.1016/j.egypro.2016.09.174. Annex75

Rose J, Thomsen KE, Domingo-Irigoyen S, Bolliger R, Venus D, Konstantinou T, Mlecnik E, Almeida M, Barbosa R, Terés-Zubiaga J, Johansson E, Davidsson H, Conci M, Mora TD, Ferrari S, Zagarella F, Sanchez Ostiz A, San Miguel-Bellod J, Monge-Barrio A, Hidalgo-Betanzos JM (2021) Building renovation at district level—lessons learned from international case studies. Sustain Cities Soc 72:103037. https://doi.org/10.1016/j.scs.2021.103037

Seddon PB, Lewis GP, Freeman P, Shanks GG (2004) The case for viewing business models as abstractions of strategy. CAIS 13:25

Sharp T, Haase M, Zhivov A, Rismanchi B, Lohse R, Rose J, Nord N (2020) Energy master planning: identifying framing constraints that scope your technology options, ASHRAE Transactions 2020, Vol 126, Part 1. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Teece, D. J. (2010). Business models, business strategy and innovation. *Long Range Planning*, *43*(2), 172–194. https://doi.org/10.1016/j.lrp.2009.07.003

Verdú FM, Tierno NR (2019) Special issue: clustering and innovation: firm-level strategizing and policy. Entrep Reg Dev 31(1–2):1–6. https://doi.org/10.1080/08985626.2018.1537143

Multicriteria Spatial Economic Decision Support Systems to Support Positive Energy Districts: A Literature Review

Adriano Bisello, Marta Bottero, Marco Volpatti, and Tiziana Binda

Abstract To meet the ambitious targets set by the European Union to reduce CO_2 emissions, action in cities is essential. In fact, cities are responsible for 67% of the world's primary energy consumption and about 70% of energy-related CO_2 emissions. To support the urban energy transition, widespread implementation of net-zero districts, or even better, positive energy districts (PEDs), is expected. PEDs could be defined as energy efficient and energy flexible urban areas that aim to provide a surplus of clean energy to the city through renewable energy. However, the development of the PED concept needs to take into account not only the technical issue of energy systems, but also the environmental, social, and economic aspects. To be effective, it is important to provide decision makers with tools based on a Multi-Criteria Decision Analysis (MCDA) approach that can effectively assess the complexity of impacts from a multi-stakeholder perspective. The MCDA approach can be supported by a Geographic Information System (GIS) that helps to analyze the data and make it communicable to everyone. The purpose of this research, through a scientific literature review, is to investigate different MCDA supported by GIS in the framework of economic evaluation methods, aiming to contribute to the definition of an effective multi-criteria spatial economic decision making method to support and sustain the design and development of PEDs.

Keywords Multi-Criteria Decision Analysis (MCDA) · Geographic Information System (GIS) · Energy transition · Positive Energy District (PED) · Economic evaluation

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1 Introduction

The European Union has placed great emphasis on reducing CO_2 emissions in cities and related systems. Cities account for more than 50% of the global population, 80% of the global GDP, two-thirds of global energy consumption and more than 70% of annual global carbon emissions (IEA 2020). These factors are expected to increase significantly in the coming decades: it is anticipated that by 2050 more than 70% of the world's population will live in cities, resulting in massive growth in demand for urban energy infrastructure (European Commission 2023). Climate action in cities is essential to achieve the ambitious net-zero emissions goals. From this perspective, it is known that urban development in the coming years will have to shift from simple building solutions to positive-energy neighbourhoods and districts (Becchio et al. 2020). All of this, along with other innovative concepts developed in the past for cities of the future, will be key to achieving Europe's energy and climate change goals (Suppa et al. 2022). With the new Horizon Europe research and innovation plan (which will cover the period 2021–2027), Europe is aiming to vigorously address a number of global challenges that affect our cities and society: health and safety, digitization, energy and climate change in the first place (Guarino et al. 2022). With this in mind, PEDs fall under this heading. The area of Smart Cities and Communities was already defined as a priority and strategic by both the previous European Horizon 2020 program and the 17 Sustainable Development Goals established by the UN and the 2030 Agenda (Kroll et al. 2019). Over time, however, it became apparent that financing large smart city projects at the urban level was a complex task, with a huge demand for resources and investment. For this reason, the authors decided to focus efforts on smaller urban areas, such as city blocks, pilot districts and neighbourhoods, towards a concept of a diffused smart land focusing initially on energy efficiency in buildings and on-site local renewable energy production. In recent years, to sustain the urban energy transition, the concept became even more ambitious, from highly efficient buildings to net-zero ones. Later on, by including energy sharing, waste heat recovery, e-mobility and energy storage, the scope was broadened to include the implementation of net-zero districts or even better PEDs (Guarino et al. 2022). PEDs represent a new approach towards a sustainable and efficient city and urbanization model. An urban Positive Energy District combines the built environment, mobility, sustainable production and consumption to increase energy efficiency and decrease greenhouse gas emissions and to create added value for citizens. Positive Energy Districts also require integration between buildings, users and various energy networks, mobility services and IT systems.

2 Context of the Research

2.1 Features of PEDs

Research all around the world is still struggling to find a unique definition for PEDs. From an energy-focused perspective, a PED is seen as an energy self-sufficient and carbon–neutral urban district. Indeed, positive energy means that energy districts also play an important role in producing excess energy using renewable energy sources and feeding it back into the grid (Bossi et al. 2020). However, widening the perspective, it is expected that PEDs will increase the quality of life in European cities, help achieve the COP21 goals and improve European capabilities and knowledge to become a global model (Derkenbaeva et al. 2022).

Moreover, considering the keen interest of the European Commission to deliver at least 100 PEDs by 2050 and the current situation of European cities (IEA 2020), it is necessary to address this concept not only for new areas of urban development and the construction of new buildings and neighbourhoods, but especially for redevelopment of the existing building stock (Derkenbaeva et al. 2022).

The discussion on how and where to define the boundaries of these entities is still open and conclusions may differ depending on whether one considers physical limits and management aspects or those related to the overall energy balance and energy carriers, ranging therefore from local to regional scale (Zhang et al. 2021; Bossi et al. 2020). The discussion also often starts from the local dimension of city blocks, up to the urban dimension. To this regard, some interesting research on existing tools to support decision-making toward climate neutrality in cities and districts has been already carried out by Suppa et al. (2022).

In an attempt for extreme simplification, it can be said that PEDs have to strike an optimal balance between energy efficiency, energy flexibility and local energy production (European Commission 2023) in turn also achieving integrated sustainability based on environmental, economic and social features (see Fig. 1) (Muñoz et al. 2020).

Consequently, in the evaluation of a PED using the model proposed by Binda et al. (2022), these four dimensions include intrinsic and extrinsic features of a PED that are intertwined without precise separation but rather highlight areas of overlap and coexistence in fuzzy logic. Economic evaluation approach tools used in the evaluation process enable decision-makers to have the effects of their decisions on the basis of selected KPIs under control. Even more, evaluation of urban projects is inspired by a circularity approach, which corresponds to the relationship between the Life Cycle Assessment (LCA) of the same projects and the overall Whole-Life Cost (WLC) (Grazieschi et al. 2020). LCA is a process to evaluate the effects a product has on the environment over the entire period of its life thereby increasing resource-use efficiency and decreasing liabilities (Grazieschi et al. 2020).

WLC is basically rooted in a monetary perspective and thus related to the economic sustainability of investments by accounting for the total expense of owning an asset over its entire life from purchase to disposal, as determined by financial analysis

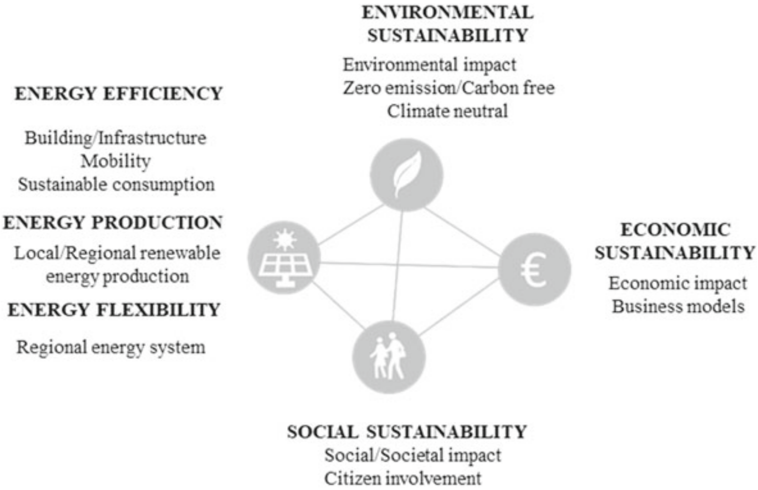

Fig. 1 The four main areas for evaluating PEDs. *Source* Own elaboration

(Fregonara 2020). The Life Cycle Cost (LCC) related to urban projects includes land acquisition and site preparation, design and building costs, operating costs, maintenance, associated financing costs, depreciation and disposal/demolition costs (Becchio et al. 2020).

As shown in Fig. 2, WLC also considers certain costs that are usually overlooked, such as factors related to environmental and social impact. In addition, we have an "extended" version of costs, which includes costs/benefits related to externalities (Becchio et al. 2020), cost savings and other effects (Fregonara 2020). This extended version includes the co-benefits commonly adopted to define the additional positive impact of smart energy renovation projects alongside the desired primary goal (Bisello 2020).

2.2 *Towards an Integrated Sustainability Evaluation*

To move from a mere economic evaluation of PEDs towards an integrated sustainability assessment (Binda et al. 2022), including the spatial dimension, in this research, two additional elements were considered: Multi-Criteria Decision Analysis (MCDA) and Geographic Information System (GIS).

As shown in Fig. 3, there are different characteristics in each circle that by complementing one another contribute to defining methods and tools. MCDA is a powerful tool that enables the concurrent evaluation of qualitative, quantitative and monetary elements (Binda et al. 2022). It is a simplified way to consider environmental social and governance (ESG) criteria (European Commission 2023). This method also

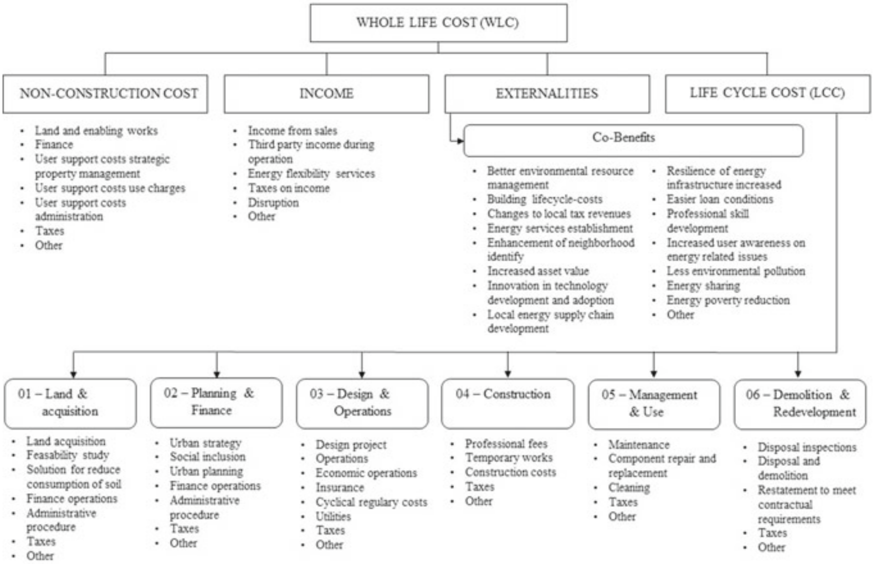

Fig. 2 Whole-life cost with externalities. *Source* Own elaboration based on Becchio et al. (2020), Bisello (2020), Fregonara (2020)

increases the transparency of the decision-making processes making the disadvantages and vantages in the alternatives clear (Bottero et al. 2021). Under this category, several different applications can be identified such as Fuzzy Multi-Criteria Decision Analysis (FMCDA), Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Multi-Criteria Decision Making (MCDM), Spatial-Multi-Criteria Analysis (SMCA) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).

GIS is important to represent and analyse geo-referred data that are used to analyse the spatial development and temporal dynamics of transformation processes and is therefore the graphical representation of the results for a suitability map (Coutinho-Rodrigues et al. 2011). These two additional elements complement the economic analysis, which focuses on setting an evaluation as the balance between overall advantages/disadvantages (Binda et al. 2022), identifying economic efficiency measures and meaning a cost-effective situation as a socially appropriate condition. Finally, a Cost Benefit Analysis (CBA) makes it possible to synthesize the performance of different evaluation aspects, transfer all impact into monetary terms (Bottero et al. 2021) and elaborate specific KPIs such as Net Present Value (NPV) or Return of investment (ROI) (Bottero et al. 2016). In this framework of economic and financial analysis, the Social Return on investment (SROI) is also becoming popular to evaluate urban projects (Hunter et al. 2022).

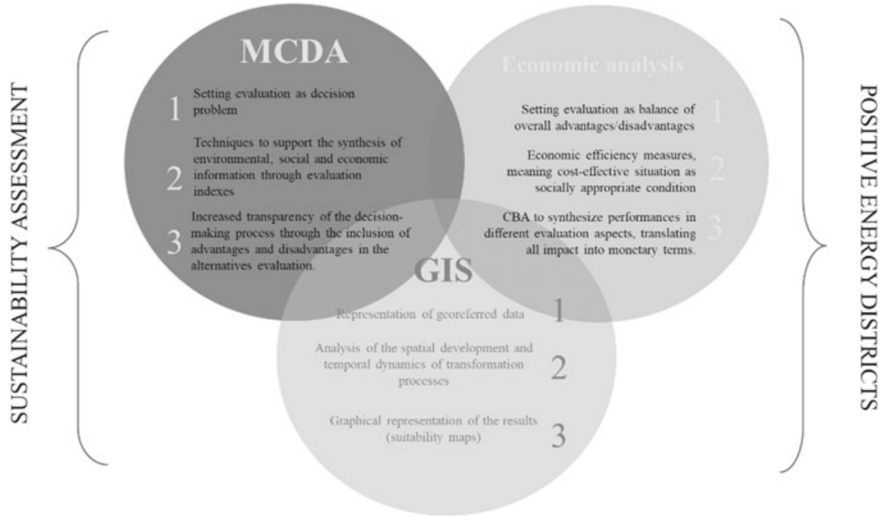

Fig. 3 Conceptual framework for Multicriteria-Spatial-Economic analysis of PED diagram (*Source* Own elaboration)

3 Research Methodology

Structure of the analysis (Fig. 4) is composed of three steps. In the first, we searched the literature from a scientific bibliographic database, in the second, we have the review based on the combination of three concepts shown in Fig. 3, and finally, the analysis phase. Literature bibliography analysis was conducted using the SCOPUS database with the following keywords in different combinations: Multicriteria, GIS, Economic. For a more informative literature review, we believe it is best to push the district boundary so as not to exclude valid methodologies for narrowings to which we have no explanation. Analysis was conducted to see how many documents are present for different combinations, specifically four combinations were found. Group A-B-C is research that shows historical production, country productivity affiliation and research topic, while Group D was conducted using more specific analysis as it is the heart of the analysis. Below are the strings used for the different groups:

1. **GROUP A**: "Multicriteria | GIS", limited research "*title, abstract, the keyword*", using the words: (*"Multicriteria" OR "Multicriteria Analysis" OR "MCDA" OR "MCA" OR "Multi-Criteria" OR "Multiple Criteria Decision Analysis"*) AND ("GIS" OR "geographic information system" OR "Spatial Decision Support System") = **4,440 documents**

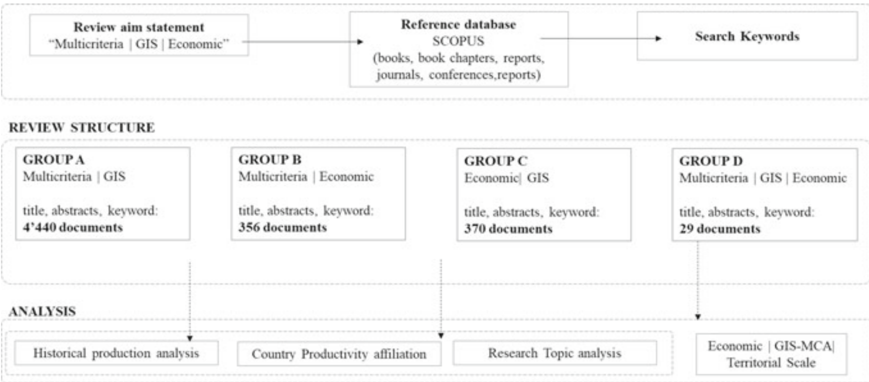

Fig. 4 Research method (*Source* Own elaboration)

2. **GROUP B**: "Multicriteria I Economic", limited research "*title, abstract, the keyword*", using the words: (*"Multicriteria" OR "Multicriteria Analysis" OR "MCDA" OR "MCA" OR "Multi-Criteria" OR "Multiple Criteria Decision Analysis"*) AND (*"economic evaluation" OR "economic valuation" OR "economic assessment"*) = **356 documents**
3. **GROUP C**: "Economic I GIS", limited research "*title, abstract, the keyword*", using the words: (*"economic evaluation" OR "economic valuation" OR "economic assessment") AND ("GIS" OR "geographic information system" OR "Spatial Decision Support System"*) = **370 documents**
4. **GROUP D** "Multicriteria I Economic I GIS", limited research "*title, abstract, the keyword*", using the words: (*"Multicriteria" OR "Multicriteria Analysis" OR "MCDA" OR "MCA" OR "Multi-Criteria" OR "Multiple Criteria Decision Analysis"*) AND ("GIS" OR "geographic information system" OR "Spatial Decision Support System") AND (*"economic evaluation" OR "economic valuation" OR "economic assessment"*) = **29 documents**

As shown in Fig. 4, to identify the research articles in group A, B, C, analysis was conducted both by year of publication of the papers, chronological order to assess the increase or decrease in techniques as the years passed, an analysis regarding publication status, and finally according to the research fields belonging to the macro fields. For group D specific analysis was conducted related to the Economic, GIS-Multicriteria and Territorial Scale.

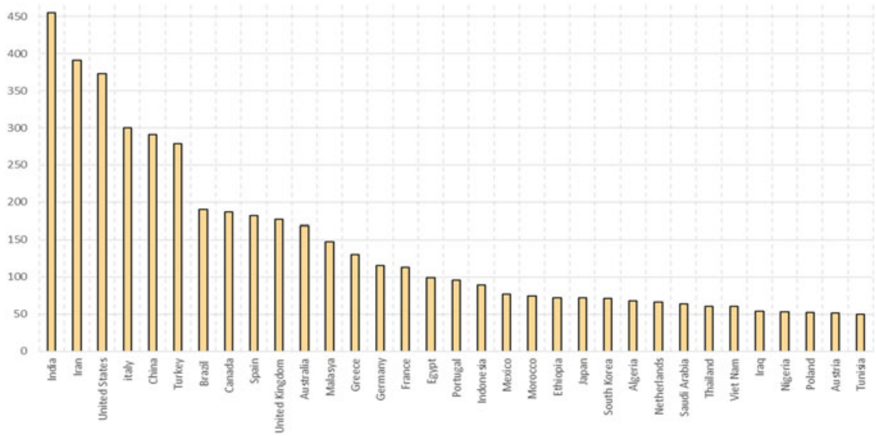

Fig. 5 Analysis by nations of publications that use multicriteria/GIS methods

4 Results

4.1 GROUP A (Multicriteria I GIS)

From the perspective of historical production analysis, this theme first appeared in 1976. Between 1976 and 1999, this theme only appeared in 18 articles. While, since 1999 production has increased with an exponential growth every year reaching 605 papers in 2021. As shown in Fig. 5, in Country Productivity Affiliation, the country that has produced the most regarding this topic is India with 455 papers, followed by Iran with 391 papers and then the United States with 373 papers.

As shown in Fig. 6 in research topic analysis, the main areas of development of this topic are Environmental Sciences, Earth, Planetary Sciences and Social Sciences with respectively, 2,121, 1,226, 1,219 and 879 papers. The energy field has only 514 papers.

4.2 GROUP B (Multicriteria I Economic)

As far as historical analysis of production is considered group B began publishing in 1981, with exponential growth, so much so that a substantial increase in publication was noted from 2005, gradually increasing to 46 items in 2021. As shown in Fig. 7, in Country of Productivity, the largest producing country in this area is Italy, producing 60 papers, followed by the United Kingdom with 41 papers and the United States with 40 papers.

As shown in Fig. 8, in the Research topic, the main research Topic of analysis regarding Group B (MCA I Economic) is Environmental Sciences with 144

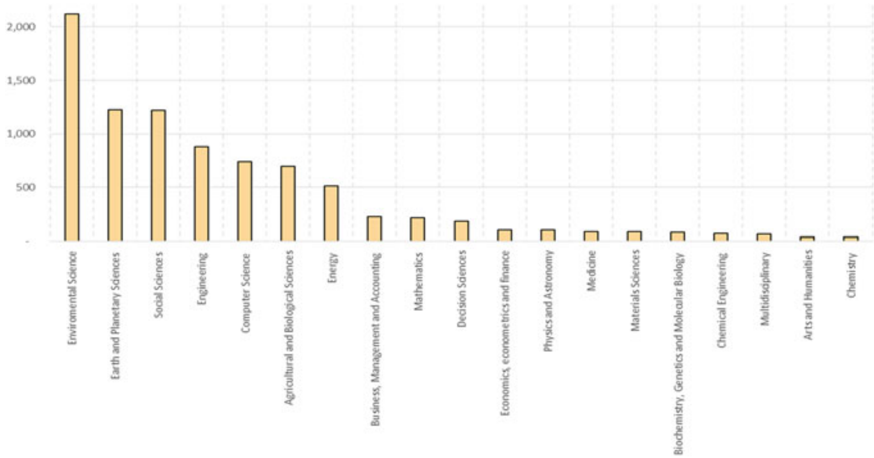

Fig. 6 Analysis by field of research of publications that uses multicriteria/GIS method

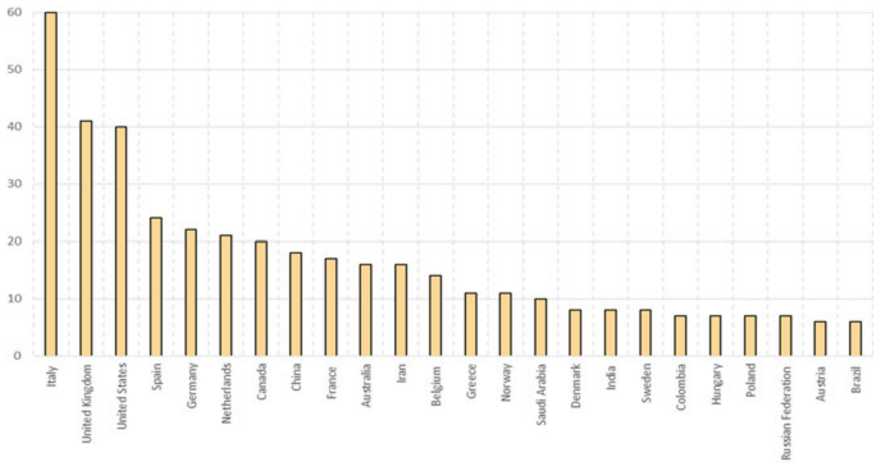

Fig. 7 Analysis by nation of publications that use multicriteria/economic

documents, followed by Engineering with 88 documents and Energy with 85 documents.

4.3 GROUP C (Economic I GIS)

This topic started to appear in 1988, and the period with the most production was 2019 with 29 documents, followed by 2017 and 2013 with 23 documents. As shown in

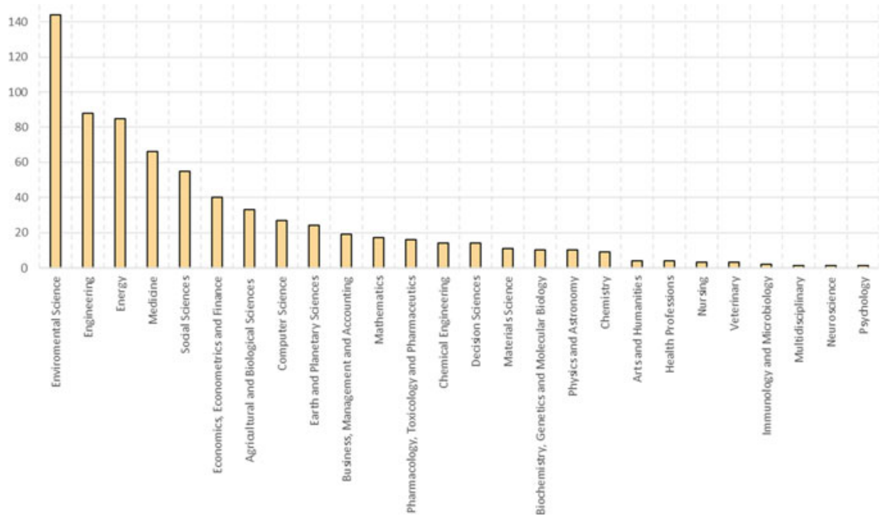

Fig. 8 Analysis by field of research of publications that uses multicriteria/economic methods

Fig. 9, in Country Analysis, the analysis showed that the United States is the country, which has produced the most documents, specifically 69 documents, followed by the United Kingdom with 40 documents and Italy with 39 documents.

As shown in Fig. 10, in Research Topic Analysis, the areas regarding this topic are Environmental Sciences with 163 documents followed by Agricultural and Biological Sciences with 71 documents and Social Sciences with 69 documents.

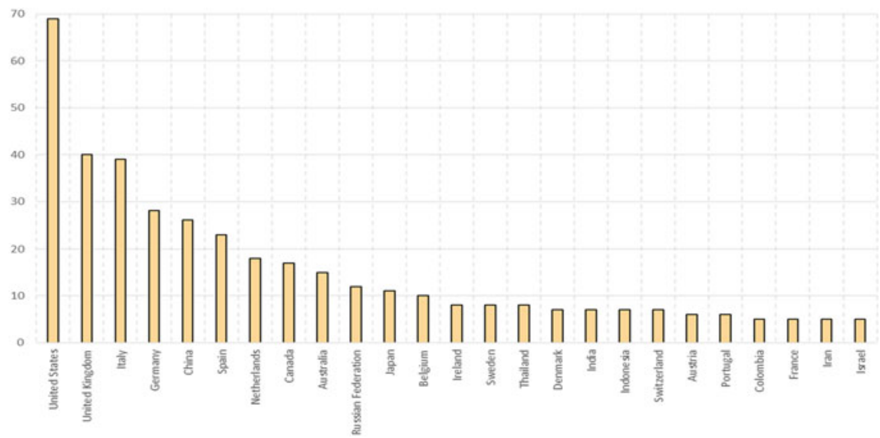

Fig. 9 Analysis by nations of publications that use economic/GIS

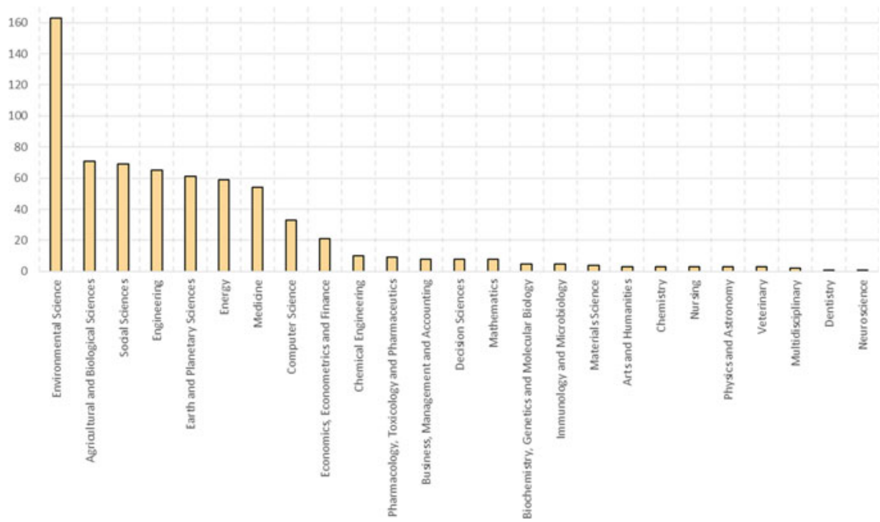

Fig. 10 Analysis by field of research of publications that use economic/GIS method

4.4 GROUP D (Multicriteria I GIS I Economic)

Group D as the main topic of research-specific analysis was conducted regarding the 28 documents related to the Economic, GIS-Multicriteria and Territorial Scale (see Table 1).

Starting with "Economic Analysis", the main economic method used is the "Techno-Economic Assessment", with 11 documents, followed by Cost Benefit Analysis (CBA) with 6 articles and Cost and Revenue Analysis with 5 documents.

There are different uses of Multicriteria Analysis and GIS. In particular, the methods found in the analysis are those which are most used in the general Weighted Combination (WC) followed by Analytic Hierarchy Process (AHP).

MCDA-WC aims to include normalized criteria that are weighted to determine the relative importance of each criterion, prioritizing some criteria over others. This is necessary to achieve a flexible decision-making method that can balance choices based on set objectives (Martín-Hernándaez et al. 2021).

MCDA AHP makes it possible to compare multiple alternatives with a plurality of criteria, either quantitative or qualitative, and derive an overall evaluation for each. This makes it possible to sort the alternatives in order of preference, select the best alternative, and ultimately be able to assign the alternatives to predefined subsets (Muñoz et al. 2020).

It became clear that all articles were divided into these three categories, namely, regional scale, city and parts of buildings. Interestingly, most of these analyses focus extensively on regional spatial contexts, which produced the majority of the documents with 21 papers, followed by "Parts of the building" with 4 documents and in the end with the "city" (Fig. 11).

Table 1 Articles combining economic analysis, GIS and MCDA for PEDs evaluation

References	Economic analysis							GIS	MCDA
	LCOE	CBA	CRA	PBP	EI	DCF	LCC		
Settou et al. (2022)	x							GIS	MCDM + WC
Martín-Hernándaez et al. (2021)	x							GIS	MCDA + WC
Mokhtara et al. (2021a)	x							GIS	MCDM + WC
Almutairi et al. (2021)	x							GIS	MCDM
Mokhtara et al. (2021b)	x							GIS	AMC
Ali and Jang (2019)	x							GIS	MCDM
Stefanakou et al. (2019)	x							GIS	MCA + WC
Cozzi et al. (2019)		x						GIS	WLC
Mansouri Kouhestani et al. (2019)	x							GIS	MCA
Madi and Srour (2019)		x						GIS	WLC + Fuzzy
Mohammadzadeh Bina et al. (2018)	x							GIS	MCDM
Kolendo and Krawczyk (2018)	x			x				GIS	AHP
Escalante et al. (2016)	x							GIS	Fuzzy + AHP
Abdul-Mawjoud and Jamel (2016)			x					GIS	AHP
Kehbila et al. (2014)			x					GIS	AMC
Li et al. (2014)		x						GIS	MCDA + WC
Restrepo-Estrada (2013)			x					GIS	MCA
De Sousa et al. (n.d.)								GIS	MCA
Agostini et al. (2012)		x						GIS	MCA
van Haaren and Fthenakis (2011)						x		GIS	MCA
Wirtz and Liu (2006)		x						GIS	MCA
Jarrar et al. (n.d.)			x					GIS	MCA

(continued)

Table 1 (continued)

References	Economic analysis							GIS	MCDA
	LCOE	CBA	CRA	PBP	EI	DCF	LCC		
Agrell et al. (2004)			x					GIS	MCA (LC)
Spiekermann and Wegener (2003)		x						GIS	MCA (LC)
Vagiona et al. (2022)								GIS	AHP + TOPSIS
Gil-García et al. (2022)	x							GIS	Fuzzy + AHP
Supapo et al. (2021)					x			GIS	TOPSIS
Muñoz et al. (2020)							x	GIS	AHP

Legend (LCOE) Levelized Cost of Electricity, (CBA) Cost Benefit Analysis, (CRA) Cost Revenue Analysis, (PBP) Pay Back Period, (EI) Environmental Impact, (DCF) Discounted Cash Flow, (LCC) Life Cycle Cost, (GIS) Geographic Information Modelling, (MCDA) Multicriteria Decision Analysis, (FMCDA) Multi-Criteria Decision Analysis, (AHP) Analytic Hierarchy Process, (ANP) Analytic Network Process, (MCDM) Multi-Criteria Decision Making, (SMCA) Spatial-Multi-Criteria Analysis, (TOPSIS) Technique for Order of Preference by Similarity to Ideal Solution. (MCDM + WC) Multi-Criteria Decision-Making Weighted Combination. (WLC) Whole-life Cost

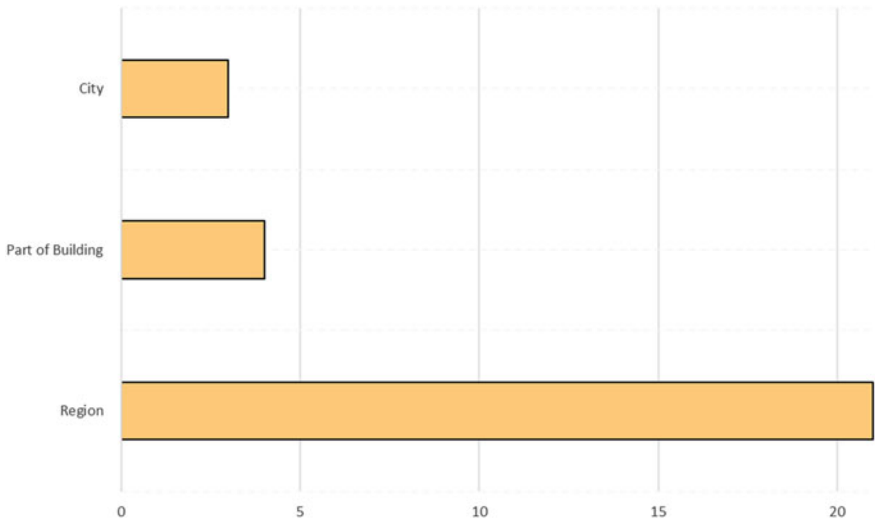

Fig. 11 Spatial reference scale of the publications considered, distinguishing between building (part of building), city-district and regional scales

5 Conclusion and Future Perspectives

The literature review of the above-mentioned elements was twofold.

Through further analysis of the scientific literature, this research can help to define an effective multi-criteria spatial economic decision-making methodology to support and sustain the design and development of PEDs. In this sense, the authors would like to investigate evaluation tools in the context of PEDs in order to understand the potential and critical elements of the available approaches to support decision-making processes in this field of application. To develop the PED concept, proper consideration must be given not only to the technical issue of energy systems but also to the environmental, social and economic spheres. To be effective, it is important to provide decision-makers with tools based on a multi-criteria decision analysis (MCDA) approach that can effectively evaluate the complexity of the impact from a multi-stakeholder perspective. The MCDA approach can be supported by a geographic information system (GIS), that helps to analyse data and make it accessible to all.

As a future outlook, however, it would be interesting to try to combine these three tools to support decision-making to identify the best area to apply PEDs to evaluate the full range of benefits of their implementation. In this regard on multiple benefit analysis to evaluate PEDs, it would be interesting to link the process of building PEDs with Building Information Modelling (BIM) implementations and District Information Modelling (DIM), to be able to support, a robust analysis as a support to the decision-making process even in the post-feasibility stages.

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References

Abdul-Mawjoud AA, Jamel MG (2016) Using the analytic hierarchy process and GIS for decision making in rural highway route location. 7:359–375

Agostini P, Pizzol L, Critto A, D'Alessandro M, Zabeo A, Marcomini A (2012) Regional risk assessment for contaminated sites. Part 3: Spatial decision support system. Environ Int 48:121–132. https://doi.org/10.1016/j.envint.2012.07.005

Agrell PJ, Stam A, Fischer GW (2004) Interactive multiobjective agro-ecological land use planning: the Bungoma region in Kenya. Eur J Oper Res 158(1):194–217. https://doi.org/10.1016/S0377-2217(03)00355-2

Ali S, Jang CM (2019) Selection of best-suited wind turbines for new wind farm sites using techno-economic and GIS analysis in South Korea. Energies 12(16). https://doi.org/10.3390/en12163140

Almutairi K, Hosseini Dehshiri SS, Hosseini Dehshiri SJ, Mostafaeipour A, Jahangiri M, Techato K (2021) Technical, economic, carbon footprint assessment, and prioritizing stations for hydrogen production using wind energy: a case study. Energ Strat Rev 36. https://doi.org/10.1016/j.esr.2021.100684

Becchio C, Bottero M, Bravi M, Corgnati S, Dell'Anna F, Mondini G, Vergerio G (2020) Integrated assessments and energy retrofit: the contribution of the Energy Center Lab of the Politecnico di Torino. In: Mondini G, Oppio A, Stanghellini S, Bottero M, Abastante F (eds) Values and functions for future cities. Springer International Publishing, pp 365–384. https://doi.org/10.1007/978-3-030-23786-8_21

Binda T, Bottero M, Bisello A (2022) Evaluating positive energy districts: a literature review. In: Calabrò F, Della Spina L, Piñeira Mantiñán MJ (eds) New metropolitan perspectives. Springer International Publishing, pp 1762–1770

Bisello A (2020) Assessing multiple benefits of housing regeneration and smart city development: the European Project SINFONIA. Sustainability 12(19). https://doi.org/10.3390/su12198038

Bossi S, Gollner C, Theierling S (2020) Towards 100 positive energy districts in Europe: preliminary data analysis of 61 European cases. Energies 13(22). https://doi.org/10.3390/en13226083

Bottero M, Assumma V, Caprioli C, Dell'Ovo M (2021) Decision making in urban development: the application of a hybrid evaluation method for a critical area in the city of Turin (Italy). Sustain Cities Soc 72:103028. https://doi.org/10.1016/j.scs.2021.103028

Bottero M, Mondini G, Oppio A (2016) Decision support systems for evaluating urban regeneration. Procedia Soc Behav Sci 223:923–928. https://doi.org/10.1016/j.sbspro.2016.05.319

Coutinho-Rodrigues J, Simão A, Antunes CH (2011) A GIS-based multicriteria spatial decision support system for planning urban infrastructures. Decis Support Syst 51(3):720–726. https://doi.org/10.1016/j.dss.2011.02.010

Cozzi M, Prete C, Viccaro M, Romano S (2019) Impacts of wildlife on agriculture: a spatial-based analysis and economic assessment for reducing damage. Nat Resour Res 28:15–29. https://doi.org/10.1007/s11053-019-09469-6

De Sousa L, Eykamp C, Leopold U, Baume O, Braun C (nd) iGUESS—a web based system integrating urban energy planning and assessment modelling for multi-scale spatial decision making. http://www.iemss.org/society/index.php/iemss-2012-proceedings

Derkenbaeva E, Halleck Vega S, Hofstede GJ, van Leeuwen E (2022) Positive energy districts: mainstreaming energy transition in urban areas. Renew Sustain Energy Rev 153:111782. https://doi.org/10.1016/j.rser.2021.111782

Escalante H, Castro L, Gauthier-Maradei P, Rodríguez De La Vega R (2016) Spatial decision support system to evaluate crop residue energy potential by anaerobic digestion. Biores Technol 219:80–90. https://doi.org/10.1016/j.biortech.2016.06.136

European Commission (2023), Consumption footprint and domestic footprint. Accessed 21 April 2023. https://doi.org/10.2760/218540

Fregonara E (2020) A life cycle perspective for infrastructure management. Aestimum 5+. https://link.gale.com/apps/doc/A662609534/AONE?u=anon~7da61072&sid=googleScholar&xid=8c0be571

Gil-García IC, Ramos-Escudero A, García-Cascales MS, Dagher H, Molina-García A (2022) Fuzzy GIS-based MCDM solution for the optimal offshore wind site selection: the Gulf of Maine case. Renew Energy 183:130–147. https://doi.org/10.1016/j.renene.2021.10.058

Grazieschi G, Asdrubali F, Guattari C (2020) Neighbourhood sustainability: state of the art, critical review and space-temporal analysis. Sustain Cities Soc 63:102477. https://doi.org/10.1016/j.scs.2020.102477

Guarino F, Bisello A, Frieden D, Bastos J, Brunetti A, Cellura M, Ferraro M, Fichera A, Giancola E, Haase M, Kantorovitch J, Neumann C, Mankaa R, Segura IL, Traverso M, Tumminia G, Volpe R, Zhang X (2022) State of the art on sustainability assessment of positive energy districts: methodologies, indicators and future perspectives. In: Littlewood JR, Howlett RJ, Jain LC (eds) Sustainability in energy and buildings 2021. Springer Nature Singapore, pp 479–492

Hunter RF, Dallat MA, Tully MA, Heron L, O'Neill C, Kee F (2022) Social return on investment analysis of an urban greenway. Cities Health 6(4):693–710. https://doi.org/10.1080/23748834.2020.1766783

IEA (2020) CO_2 emissions in MT by sector, world 1990–2018. https://Www.Iea.Org/Data-and-Statistics

Jarrar A, Jayasuriya N, Othman M, Jayyousi A (nd) Integrated natural resources management framewrok in semi-arid regions

Kehbila AG, Alemagi D, Minang PA (2014) Comparative multi-criteria assessment of climate policies and sustainable development strategies in Cameroon: towards a GIS decision-support tool for the design of an optimal REDD+ strategy. Sustainability (Switzerland) 6(9):6125–6140. https://doi.org/10.3390/su6096125

Kolendo Ł, Krawczyk DA (2018) Spatial and economic conditions of the solar energy use in single-family houses—a case study. In: MATEC web of conferences, vol 174.https://doi.org/10.1051/matecconf/201817401038

Kroll C, Warchold A, Pradhan P (2019) Sustainable development goals (SDGs): are we successful in turning trade-offs into synergies? Palgrave Commun 5(1):140. https://doi.org/10.1057/s41599-019-0335-5

Li D, Zhang C, Pizzol L, Critto A, Zhang H, Lv S, Marcomini A (2014) Regional risk assessment approaches to land planning for industrial polluted areas in China: the Hulunbeier region case study. Environ Int 65:16–32. https://doi.org/10.1016/j.envint.2013.12.004

Madi N, Srour I (2019) Managing emergency construction and demolition waste in Syria using GIS. Resour Conserv Recycl 141:163–175. https://doi.org/10.1016/j.resconrec.2018.10.018

Mansouri Kouhestani F, Byrne J, Johnson D, Spencer L, Hazendonk P, Brown B (2019) Evaluating solar energy technical and economic potential on rooftops in an urban setting: the city of Lethbridge, Canada. Int J Energy Environ Eng 10(1):13–32. https://doi.org/10.1007/s40095-018-0289-1

Martín-Hernándaez E, Martín M, Ruiz-Mercado GJ (2021) A geospatial environmental and techno-economic framework for sustainable phosphorus management at livestock facilities. Resour Conserv Recycl 175. https://doi.org/10.1016/j.resconrec.2021.105843

Mohammadzadeh Bina S, Jalilinasrabady S, Fujii H, Farabi-Asl H (2018) A comprehensive approach for wind power plant potential assessment, application to northwestern Iran. Energy 164:344–358. https://doi.org/10.1016/j.energy.2018.08.211

Mokhtara C, Negrou B, Settou N, Bouferrouk A, Yao Y (2021a) Optimal design of grid-connected rooftop PV systems: an overview and a new approach with application to educational buildings in arid climates. Sustain Energy Technol Assess 47. https://doi.org/10.1016/j.seta.2021.101468

Mokhtara C, Negrou B, Settou N, Settou B, Samy MM (2021b) Design optimization of off-grid hybrid renewable energy systems considering the effects of building energy performance and climate change: case study of Algeria. Energy 219. https://doi.org/10.1016/j.energy.2020.119605

Muñoz I, Hernández P, Pérez-Iribarren E, Pedrero J, Arrizabalaga E, Hermoso N (2020) Methodology for integrated modelling and impact assessment of city energy system scenarios. Energ Strat Rev 32. https://doi.org/10.1016/j.esr.2020.100553

Restrepo-Estrada C (2013) Usos óptimos del suelo bajo enfoques ambientales y económicos/ Optimal land use under environmental and economic approaches. Revista Facultad de Ingeniería 229–243

Settou B, Settou N, Gahrar Y, Negrou B, Bouferrouk A, Gouareh A, Mokhtara C (2022) Geographic information-driven two-stage optimization model for location decision of solar power plant: a case study of an Algerian municipality. Sustain Cities Soc 77. https://doi.org/10.1016/j.scs.2021.103567

Spiekermann K, Wegener M (2003) Modelling urban sustainabilty. Int J Urban Sci 7:47–64. https://doi.org/10.1080/12265934.2003.9693522

Stefanakou AA, Nikitakos N, Lilas T, Pavlogeorgatos G (2019) A GIS-based decision support model for offshore floating wind turbine installation. Int J Sustain Energ 38(7):673–691. https://doi.org/10.1080/14786451.2019.1579814

Supapo KRM, Lozano L, Tabañag IDF, Querikiol EM (2021) A geospatial approach to energy planning in aid of just energy transition in small island communities in the Philippines. Appl Sci (Switzerland) 11(24). https://doi.org/10.3390/app112411955

Suppa AR, Cavana G, Binda T (2022) Supporting the EU Mission "100 climate-neutral cities by 2030": a review of tools to support decision-making for the built environment at district or city scale. In: Gervasi O, Murgante B, Misra S, Rocha AMAC, Garau C (eds) Computational science and its applications—ICCSA 2022 workshops. Springer International Publishing, pp 151–168

Vagiona DG, Tzekakis G, Loukogeorgaki E, Karanikolas N (2022) Site selection of offshore solar farm deployment in the Aegean Sea, Greece. J Mar Sci Eng 10(2). https://doi.org/10.3390/jmse10020224

van Haaren R, Fthenakis V (2011) GIS-based wind farm site selection using spatial multi-criteria analysis (SMCA): evaluating the case for New York State. In: Renewable and sustainable energy reviews, vol 15, no 7, pp 3332–3340. Elsevier Ltd. https://doi.org/10.1016/j.rser.2011.04.010

Wirtz KW, Liu X (2006) Integrating economy, ecology and uncertainty in an oil-spill DSS: the Prestige accident in Spain, 2002. Estuar Coast Shelf Sci 70(4):525–532. https://doi.org/10.1016/j.ecss.2006.06.016

Zhang X, Penaka SR, Giriraj S, Sánchez MN, Civiero P, Vandevyvere H (2021) Characterizing positive energy district (PED) through a preliminary review of 60 existing projects in Europe. Buildings 11:318. https://doi.org/10.3390/buildings11080318

A Holistic Sustainability Evaluation of Positive Energy Districts—Planetary Boundaries Framing the Transformation of Districts

Matthias Haase and Daniela Baer

Abstract The development of districts requires a distinct understanding of the current situation as well as a vision of future districts to be able to develop suitable pathways for a sustainable transition. The concept of Positive Energy Districts (PEDs) is one of the main initiatives in Europe for the clean energy transition in the built environment. While PEDs are mainly heading for the energy transition, little is known how they relate to the holistic concept of planetary boundaries (PB). To be able to build representative methodology for sustainability assessment of PEDs as well as define comparable, measurable, and reliable indicators specifically targeted for the district scale, we take a closer look at the concept of PB in order to analyze how this concept can help to establish a holistic sustainability evaluation of PEDs. Below we present an analysis of two PED concepts to discuss their interrelation with the PB concept. Our research is based on literature and document analysis. We identify the need for a comprehensive understanding of the different aspects impacting the sustainability assessment of PEDs. In this sense, although highly advisable, an integrated and systemic approach to the sustainability assessment of PEDs has still not been consolidated and the main environmental, economic, and social pillars are usually treated as separate spheres with limited interlinked issues.

Keywords Planetary boundaries · Sustainability evaluation · Positive energy districts

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1 Introduction

Several initiatives in Europe aim for the clean energy transition in the built environment. The concept of Positive Energy Districts (PEDs) is advocated by energy policies and international working groups to accelerate the decarbonization of urban areas and promote the potential for scalability between cities. To be able to plan a district with a positive perspective of its attributes, it is mandatory to establish a new framework based on a list of key performance indicators (KPIs). Planetary boundaries (PB) define the boundaries of the "planetary playing field" for humanity if major human-induced environmental change on a global scale is to be avoided. Transgressing one or more PB could be highly damaging or even catastrophic due to the risk of crossing thresholds that trigger non-linear, abrupt environmental change within continental- to planetary-scale systems. Identifying the PB can therefore be used as an approach towards a new framework for PEDs based on a good understanding of the PB, i.e., towards an estimation of the safe space for human development. In this sense, it is interesting to study these PB in relation to district developments, namely, the new concept of PEDs.

In this paper, we address the need for a comprehensive understanding of the different aspects impacting the sustainability assessment of PEDs. In this sense, although highly advisable, an integrated and systemic approach to the sustainability assessment of PEDs has still not been consolidated and the main environmental, economic, and social pillars are usually treated as separate spheres with limited interlinked issues. To be able to build representative methodology for sustainability assessment of PEDs as well as define comparable, measurable, and reliable indicators specifically targeted for the district scale we take a closer look at the concept of PB to find out how this concept can help to establish a holistic sustainability evaluation of PEDs. There are three important key questions:

- Can the concept of PB be used when planning PEDs?
- How does the PED concept relate to PB?
- Which other boundaries are important for PEDs?

2 Background

2.1 Positive Energy District Activities

PEDs are the main focus of several activities on a European scale as well as the focus of international research by the International Energy Agency Energy in Buildings and Construction Annex 83 "Positive Energy Districts". Although a common and comprehensive definition is still being widely discussed, it is generally accepted that Positive Energy Districts are specific areas with annual net zero energy import and net zero CO_2 emissions, working towards an annual local surplus production of renewable energy. These districts are a key part of the transformative process from carbon-intensive cities towards sustainable urban development through a diverse set of solutions, including technological ones (building interaction, ICT, mobility, low-carbon building materials and technologies) as well as legal, economic and social ones (Annex 83).

PEDs are significant for their innovative capacity, at the same time they also present, challenges as well as opportunities for local and global sustainable development (Cost Action PED-EU-NET). The actual impact of PEDs over local sustainable development targets, meanwhile, remains uncertain. This is mainly because "*intangible elements abound in the environmental, social, cultural and institutional perspectives of sustainable development beyond the economic one and in the open, complex and dynamic ecosystems that constitute the cities in which these technologies are deployed*" (Set Plan). To support monitoring of relevant projects and initiatives, Key Performance Indicators (KPIs) can be useful tools to evaluate the progress of PEDS or smart city strategies in general as, when chosen correctly make it possible to model and describe complex phenomena through quantitative and qualitative indicators (EU WG) effectively. In a recent study, the sustainability assessment of PEDs was analyzed (Guarino et al. 2021). It was found that the field is still largely fragmented despite the fact it is fundamental to support the clean energy transition of the built environment.

2.2 PB Thresholds

PB is a concept describing earth system processes that contain environmental boundaries. It was proposed in 2009 by Johan Rockström from the Stockholm Resilience Centre and Will Steffen from the Australian National University (Rockström et al. 2009a). The framework is based on scientific evidence that human actions have become the main driver of global environmental change since the Industrial Revolution. The intention was to define a "*safe operating space for humanity*" for the international community, including governments on all levels, international organizations, civil society, the scientific community, and the private sector, as a precondition for sustainable development.

According to the PB concept, "*transgressing one or more planetary boundaries may be deleterious or even catastrophic due to the risk of crossing thresholds that will trigger non-linear, abrupt environmental change within continental-scale to planetary-scale systems*" (Rockström et al. 2009a). Earth system process boundaries mark a safe zone for the planet to the extent that they are not crossed. As of 2009, two boundaries had already been crossed, while others were in imminent danger of being crossed (Rockström et al. 2009a). However, an update from Steffen et al. (2015) suggests that four of the boundaries have been crossed: "*climate change, loss of biosphere integrity, land-system change, altered biogeochemical cycles (phosphorus and nitrogen)*" (Steffen et al. 2015).

In the PB concept, the threshold, or tipping point, is the value at which a very small increase in a control variable (like CO_2) triggers a larger, possibly catastrophic,

Table 1 PBs and their relevance for PEDs (Rockström et al. 2009a)

Earth-system process	Control variable	Threshold crossed
1. Climate change	Atmospheric carbon dioxide concentration (ppm)	Yes
	Alternatively: Increase in radiative forcing (W/m^2) since the start of the industrial revolution (~1750)	Yes
2. Biodiversity loss	Extinction rate (number of species per million per year)	Yes
3. Biogeochemical	(a) anthropogenic nitrogen removed from the atmosphere (millions of tons per year)	Yes
	(b) anthropogenic phosphorus going into the oceans (millions of tons per year)	No
4. Ocean acidification	Global mean saturation state of calcium carbonate in surface seawater (omega units)	No
5. Land use	Land surface converted to cropland (percentage)	No
6. Freshwater	Global human consumption of water (km^3/yr)	No
7. Ozone depletion	Stratospheric ozone concentration (Dobson units)	No
8. Atmospheric aerosols	Overall particulate concentration in the atmosphere, on a regional basis	Not yet quantified
9. Chemical pollution	Concentration of toxic substances, plastics, endocrine disruptors, heavy metals, and radioactive contamination in the environment	Not yet quantified

change in the response variable (global warming) through feedback to the natural earth system itself. The threshold points are difficult to locate because the earth system is very complex. Instead of defining the threshold value, a range was established where the threshold is supposed to lie inside it. The lower end of that range is defined as the boundary. Therefore, it defines a "safe operating space", in the sense that as long as we (mankind) are below the boundary, we are below the threshold value (Table 1). If the boundary is crossed, we enter a danger zone (Rockström et al. 2009a).

2.3 *Interaction Between Boundaries*

A PB may interact in a manner that changes the safe operating level of other boundaries. Rockström et al. (2009a) did not analyze such interactions but they suggested that many of these interactions will reduce rather than expand the proposed boundary levels (Rockström et al. 2009a). For example, the land use boundary could shift downward if the freshwater boundary is breached, causing lands to become arid and unavailable for agriculture. At a regional level, water resources may decline in Asia if deforestation continues in the Amazon. Such considerations suggest the need for "*extreme caution in approaching or transgressing any individual planetary boundaries*" (Rockström et al. 2009b).

3 Methodology

We collected data from literature on the PB concept and compared it with data collected from two PED concepts in Norway and Switzerland. Two PED concepts were analyzed relating to the methodology development and KPIs used to evaluate PEDs. These key aspects were used to analyze the PED framework (in the Norwegian and Swiss PED) relation to PB. As a result, those measures were identified which support the PB concept and those which should be analyzed further.

3.1 Two PED Concepts and Their Sustainability Assessments

Two PED concepts are presented, the 2000-W Site (2000WS) from Switzerland and the Zero Emission Neighborhood (ZEN) concept from Norway (Haase 2021; Wiik et al. 2018).

4 2000-W-Site

The 2000-W-Site (2000WS) is a new concept developed in Switzerland resulting in new forms of settlements (Haase 2021). It has gained a reputation for energy efficiency, renewable energies, and climate friendliness and reflects the values of a responsible society. The core idea of the 2000-W Site is an ongoing evaluation process of a site's sustainability in terms of energy consumption and production in development, planning, implementation, and operations of the district. Certificates that document the status of development/sustainability progress are issued for a limited time period and must be renewed periodically. They are awarded in two stages: As a "site under development" until at least half of the total living space is in use, and after completion as a "site in operation". The concept of a 2000WS takes an integrative view of the entire site rather than individual buildings by depicting the whole living environment. The subject areas of the criteria to evaluate 2000WS are shown in Table 2.

5 Zero Emission Neighborhoods

Already in 2008, the Norwegian Parliament decided that Norway should become "carbon neutral" by 2050 and recently Norway enhanced its nationally determined contribution under the Paris Agreement to reduce emissions by at least 50% and as much as 55% compared to 1990 levels by 2030 (Norwegian Ministry of Climate and Environment 2019).

Table 2 Evaluation criteria of the 2000WS certification scheme

Subject area	Key performance indicators
1. Management system	Structure of area ownership for planning, realization and operations, goal agreement, long-time monitoring system, contract for reaching goals, monitoring operational energy and mobility services, quality management system
2. Communication, cooperation, participation	Stakeholder analysis and involvement, the possibility for dialogue and to exchange feedback, participative rules, user-related information and specific offers on energy and mobility-related topics
3. Site utilization and urban planning	Integration in urban development, integrated district, and outdoor concept, urban climate strategy with a focus on ventilative cooling, avoidance of heat islands, semi-public spaces on the ground floor, common spaces inside, on roofs and loggias, public access to green spaces with high "staying" quality, on-site or nearby offers for goods and services tailored to user needs
4. Supply and waste disposal	Locally produced high ecological quality energy, local renewable heat and electricity generation and self-consumed electricity, end energy with high ecological quality (100% renewable of which 50% is eco-labeled electricity (nature made star or equal), tailor-made water concept incl. monitoring drinking water with a feedback loop and a phase-conform waste management concept with monitoring, feedback and an improvement loop
5. Buildings	Mandatory LCC, participative quality competition for sites within the urban setting, optimized construction, building operations, and mobility in terms of sustainable building principles, moderate (low) people per area, and flexible use of onsite areas
6. Mobility	Minimized parking areas with operating concepts that cross-finance public transport, optimized bicycle parking areas with good access and high quality, good footpath and bicycle lane networks, good connections to other footpath networks and bicycle lanes, barrier-free, attractive offers for public transport with well-designed stops and connections, combined mobility concepts for users, car-sharing pools with user-centric combination offers

There is no specific regulation for PEDs in general so the policy framework consists of different laws and regulations, guiding principles, white papers, and standards that influence the implementation of PEDs. While municipal goals are set on regional and urban scales through climate and energy plans, goals for buildings and blocks of buildings are set by their individual owners. Setting energy and emission goals at an intermediate level between city and buildings is a new approach in Norway and was mainly developed through the research center for Zero Emission Neighborhoods in Smart Cities, which is a frontrunner in developing this new research perspective in Norway. A Zero emission neighborhood aims to reduce its

Table 3 Evaluation criteria of ZEN demo sites (Wiik et al. 2018)

Criteria	Key performance indicators
GHG emission	Total GHG emissions in $tCO_2eq/m^2BRA/a$; $kgCO_2eq/m^2BAU/a$; tCO_2eq/capita GHG emission % reduction compared to the base case
Energy	Energy efficiency in buildings (Energy efficiency in buildings, Net energy need in $kWh/m^2BRA/a$; Gross energy need in kWh/m^2BRA) Energy carrier (Energy use in kWh/a; Energy generation in kWh/a; Delivered energy in kWh/a; Exported energy in kWh/a; Self-consumption in %; Self-generation in %; Color coded carpet plot in kWh/a)
Power/ load	Power/load performance (Netload early profile in kW; Net load duration curve in kW; Peak load in kW; Peak export in kW; Utilization factor in %) Power/load flexibility (Daily net load profile in kW)
Mobility	Mode of transport (% share) Access to public transport (Meters; Frequency)
Economy	Life cycle cost (LCC) (NOK; $NOK/m^2BRA/a$; $NOK/m^2BAU/a$; NOK/capita)
Spatial qualities	Demographic needs and consultation plan (Qualitative) Delivery and proximity to amenities (Number of amenities, Meters (distance from buildings); Public space (Qualitative)

direct and indirect GHG emissions to zero over its lifespan. At the time of writing, a neighborhood is defined within the ZEN center as a group of interconnected buildings with associated infrastructure, located within a confined geographical area (Wiik et al. 2018) The ZEN definition is still under development but a framework of KPIs in six respective categories, namely, GHG emissions, energy, power/load, mobility, economy, and spatial qualities, is already in place (see Table 3).

Similar to the 2000WS concept, Norwegian districts will be assessed using these KPIs with a multi-criterial analysis. The results document the status of development towards zero emission neighborhoods and will help stakeholders involved to adapt plans, designs, and operating assets towards more sustainable patterns.

6 2000-W-Site and ZEN—Two PED Concepts and Their Sustainability Assessment

From the key performance indicators in PEDs (Tables 2 and 3), it is clear that two main indicators can be related to PB in PEDs. Firstly, to be able to mitigate further degradation of the climate system, it is mandatory to radically reduce GHG emissions. This not only includes reducing the energy consumption through conservation and efficiency but it also means switching to clean energy sources as well as reducing embodied carbon throughout supply chains and designing in general terms without waste generation.

PEDs as well as larger built environments also contribute to GHG emissions by embodied carbon in the built environment. Construction material use and its related embodied emissions as well as mobility both contribute to operational and embodied GHG emissions. IF green spaces are integrated into PEDs they can have a positive influence on reducing surface temperatures (urban heat island effect) and in addition on the operational energy and GHG emissions associated with cooling buildings and spaces in PEDs. In PED buildings, operational energy in both new builds and retrofits can be improved with efficient ventilation systems and passive and low temperature heating and cooling. In addition, efficient and natural lighting strategies and optimized building envelopes in co-design with efficient appliances have shown the potential to reduce operational energy. Embodied GHG emissions on the other hand can be minimized by reducing material use and choosing nature-based materials and circular processes. In PED, operating performance can be further improved with design considerations and innovation, and material demand can be reduced through increased efficiency. This requires that materials must be optimized throughout their lifecycle to reduce carbon in terms of their origin, extraction, processing and end of life considerations. This also includes material innovations such as low-carbon concrete and strategies such as designing for reuse.

One possibility for material choice in PED planning and construction processes is sustainable material sourcing such as timber sourced from sustainably managed, biodiverse plantation forests to avoid the degradation of old growth areas to maximize carbon sequestration. Where useful, fast-growing bio-based materials such as bamboo and hemp can be used as alternatives to timber.

Secondly, PEDs have a direct impact on land use change through constraints on urban growth by making better use of already converted land to prevent urban sprawl and land and forest degradation. How transport and infrastructure are planned directly influences further deterioration of the quality of forest land, especially of old forests. City governments and utilities can develop PED policies and invest directly in protecting and restoring their local forested catchments to improve the delivery of ecosystem services, including improving water quality and seasonal river resilience: lower flood risk downstream; temperature control; improve biological diversity and increase cultural value.

7 Discussion

As the focus of this work was to take a closer look at the concept of PB to find out how this concept can help to establish a holistic sustainability evaluation of PEDs, we found that the concept of PB can be used when planning PEDs. When analyzing the key performance indicators of PED concepts (Table 4), it became clear that there are two PBs that are directly related to the indicators used in the PEDs:

- Climate change
- Land use

Table 4 PB in PEDs

PB	ZEN	2000 W areal
A. Climate change		
CO_2 concentration in the atmosphere <350 ppm and/or a maximum change of +1 W/m^2 in radiative forcing	Total GHG emissions in $tCO_2eq/m^2BRA/a$; $kgCO_2eq/m^2BAU/a$; tCO_2eq/capita, GHG emission reduction % reduction compared to the base case	The basis forms the calculation that for every person on earth, 2000 Watts of continuous power (primary energy) are available. The CO_2 emissions caused by this level of energy consumption must not exceed 1 ton per person per year
	Zero emission in all phases not only operations, building on LCA and incorporating embodied emissions; Assessment of materials with the help of the Environmental Product Declaration (EPD)	Optimized construction, building operation and mobility in terms of sustainable building principles
	Energy efficiency in buildings (Energy efficiency in buildings, Net energy need in $kWh/m^2BRA/a$; Gross energy need in kWh/m^2BRA)	Optimized construction, building operation, and mobility in terms of sustainable building principles
	Energy carrier (Energy use in kWh/a; Energy generation in kWh/a; Delivered energy in kWh/a; Exported energy in kWh/a; Self-consumption in %; Self-generation in %;color coded carpet plot in kWh/a)	

(continued)

Table 4 (continued)

PB	ZEN	2000 W areal
	Renewable energy Peak load in kW; Peak export in kW; Utilization factor in %)	Renewable energy onsite, locally produced high ecologica Renewable energy onsite, locally produced high ecological quality energy, local renewable heat and electricity generation and self-consumed electricity, end energy with high ecological quality (100% renewable of which 50% is eco-labeled electricity (nature made star or equally),l quality energy, local renewable heat and electricity generation and self-consumed electricity, end energy with high ecological quality (100% renewable of which 50% is eco-labeled electricity (nature made star or equally)
	Mode of transport (% share);Access to public transport (Meters; Frequency)	Minimized parking areas with operating concepts that cross-finance public transport (incl. differentiated user profiles), optimized bicycle parking areas with good access and high quality, good footpath and bicycle lane networks onsite, good connections to other footpath networks and bicycle lanes, barrier-free, attractive offers for public transport with well-designed stops and connections, combined mobility concepts for all users, car-sharing pools with user-centric combination offers
B. Land use		
<15% of the ice-free land surface under cropland	Requirements to establish spatial qualities that do affect the sustainable behavior of users of the neighborhood; set of KPIs on urban spatial patterns	Integration in urban development, integrated districts, and outdoor concepts, urban climate strategy with focus on ventilative cooling and avoidance of heat islands, semi-public spaces on the ground floor, common spaces inside, on roofs and loggias, public access to green spaces with high "staying" quality, on-site or nearby offers for goods and services tailored to user needs
	Assessment of materials with the help of the Environmental Product Declaration (EPD) to assess GHG	Sustainable materials and circular principles, a phase-conform waste management concept with monitoring,feedback and an improvement loop
	KPIs on density to reduce land use	Sustainable materials and circular principles, a phase-conform waste management concept with monitoring, feedback and an improvement loop

In the following, we discuss further how the PED concept relates to PB and which other boundaries might be important when planning PEDs.

7.1 How Does the PED Concept Relate to PB?

Climate change has significant consequences for all socio-ecological systems and as we have seen has a cascading effect on other boundaries.

Reducing GHG emissions is key to returning to a safe operating space. PEDs and cities when planned with PB in mind have the potential to reduce their GHG emissions by drastically reducing operational and embodied GHG emissions. Integrating green spaces into PEDs can help to capture and store CO_2 to reduce the urban heat island effect and thus energy demands related to cooling.

The other element is land use area, which is obviously a central element of PEDs. Only the transformation of existing districts would not use land, all other developments use land and thus contradict the fifth PB. Eventually, the use of green roofs (and facades) could be counted as cropland and have a positive influence.

7.2 Which Other PB Are Important for PEDs?

Freshwater:

Embedding local water cycle considerations in PED planning and design processes can support global freshwater quality. The impact of PEDs on freshwater use can further be enhanced by improving water efficiency and conservation and selecting building materials and products with low water inputs. The resilience of water sources can also be improved by proactively managing or mimicking natural water processes with nature-based solutions.

Biodiversity loss:

PEDs can improve biosphere quality and mitigate further loss by reducing embodied ecological impacts in materials, food, and other products; maximizing the quantity and quality of urban habitats; and planning linear infrastructure to protect, restore, and connect habitats.

Aquatic biodiversity can be influenced by the water quality in PEDs. Reducing contaminated runoff as well as preventing untreated sewage discharge and reducing water use can improve biodiversity in these surroundings.

The urban infrastructure of PEDs has an influence on nutrient flows to balance or close complete cycles. The nutrients in sewage slurry, food, and yard waste can become an added value rather than a cost if appropriately managed. In PEDs, these can be converted into biogas through anaerobic digestion. The produced digestate can be used as a fertilizer and soil amendment to improve soil health, reducing the need for chemical fertilizer. In PEDs, local facilities can be integrated that enable these circular nutrient flows. PEDs can reduce indirect nutrient pollution from agricultural imports through sustainable food sourcing and by scaling up local food production.

Aerosol pollution:

There is the possibility in PEDs to reduce aerosol pollution by mitigating major sources of particulate emissions including the use of fossil fuel combustion for energy, transport, and industry, and minimizing construction and demolition dust. Electrified heating and cooling, transport, cooking, and industry can reduce local emissions in PEDs.

8 Conclusions

The discussion highlights the need for a comprehensive understanding of the different aspects impacting sustainability in terms of PB of PEDs.

The study of the two PED cases in Norway and Switzerland showed that both concepts do not focus on the PB. In the case in Norway, a set of KPIs was developed that mainly tries to minimize impact compared to a "base case". Then certain measures can be used to offset the impact (e.g., the renewable electricity produced onsite can be used to offset GHG emissions from the grid). This concept is therefore heading for a better than usual approach and not congruent with the PB approach, which is framing precise thresholds for development. In Switzerland, on the other hand, the PED concept of 2000 WS does not try to stay within the PB. On the contrary, a 2000 W power use is allowed for every citizen. Even though this implies a very small footprint, it allows certain PB to reach and crossover.

There are two aspects that need to be integrated: First, starting with PEDs, there should be a focus on a regenerative model for the built environment that allows us to plan the built environment to stay within the PB. Incorporating PB into environmental and sustainability assessments in PED projects is imperative. This requires PB thresholds to be downscaled to a manageable PED scale.

Secondly, the overshoot of several PB indicates that we need to develop strategies to regenerate the Earth system and how we impact it. This will require a fundamental shift in the way we think about our relationship with the planet. We have to re-think what a balanced human–planet relationship might look like and define PB that limit our impact on the earth system.

In conclusion, the concept of PB can help to establish a holistic sustainability evaluation of PEDs as a framework for the transformation of districts. However, it seems a concerted effort is needed to integrate the nine PB into PED sustainability evaluation schemes. The KPIs used in PEDs need to include the PB if we want to use PED developments to stay within the PB.

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References

Boers N (2021) Observation-based early-warning signals for a collapse of the Atlantic meridional overturning circulation. Nat Clim Chang 11:680–688. https://doi.org/10.1038/s41558-021-01097-4

Cost Action PED-EU-NET. https://pedeu.net/. Access date 26 January 2023

EU Implementation Working Group on positive energy districts and neighbourhoods for sustainable urban development (PED). https://setis.ec.europa.eu/implementing-actions/positive-energy-districts_en#relevant-links

Guarino F, Bisello A, Frieden D, Bastos J, Brunetti A, Cellura M, Ferraro M, Fichera A, Giancola E, Haase M, Kantorovitch J, Neumann C, Mankaa R, Segura IL, Traverso M, Tumminia G, Volpe R, Zhang X (2021) State of the art on sustainability assessment of Positive Energy Districts: methodologies, indicators and future perspectives. In: Proceedings of international conference on sustainability in energy and buildings (SEB-20). http://seb-20.kesinternational.org/

Haase M (2021) Energy issues in building and district assessment schemes and benchmarking systems. In: REAL-CORP conference, 7–10 Sep 2021, Vienna, Austria. https://archive.corp.at/cdrom2021/papers2021/CORP2021_89.pdf

IEA EBC Annex83 Positive Energy Districts. https://annex83.iea-ebc.org/. Access 26 January 2023

Norwegian Ministry of Climate and Environment (2019) Norway's National Plan related to the Decision of the EEA Joint Committee No. 269/2019 of 25 October 2019. Available at: https://www.regjeringen.no/contentassets/4e0b25a4c30140cfb14a40f54e7622c8/national-plan-2030_version19_desember.pdf. Accessed 12 January 2022

Rockström J, Steffen W, Noone K et al (2009a) A safe operating space for humanity. Nature 461:472–475. https://doi.org/10.1038/461472a

Rockström J, Steffen W, Noone K, Persson Å, Chapin FS III, Lambin E, Lenton TM, Scheffer M, Folke C, Schellnhuber H, Nykvist B, De Wit CA, Hughes T, van der Leeuw S, Rodhe H, Sörlin S, Snyder PK, Costanza R, Svedin U, Falkenmark M, Karlberg L, Corell RW, Fabry VJ, Hansen J, Walker B, Liverman D, Richardson K, Crutzen P, Foley J (2009b) Planetary boundaries:exploring the safe operating space for humanity. Ecol Soc 14(2):32

SET-Plan ACTION n°3.2 Implementation Plan—Europe to become a global role model in integrated, innovative solutions for the planning, deployment, and replication of Positive Energy Districts. https://jpi-urbaneurope.eu/wp-content/uploads/2021/10/setplan_smartcities_implementationplan-2.pdf

Steffen W, Richardson K, Rockström J, Cornell SE, Fetzer I, Bennett EM, Biggs R, Carpenter SR, De Vries W, De Wit CA, Folke C (2015) Planetary boundaries: guiding human development on a changing planet. Science 347(6223):1259855

Wiik MRK, Mamo Fufa S, Baer D, Sartori I, Andresen I (2018) The ZEN definition—a guideline for the ZEN pilot areas. Version 1.0. ZEN project report (11). SINTEF Academic Press, Oslo

Regional Metabolism: A Material and Product Flow Accounting Model for Trentino, Italy

Joana Bastos and Leonardo Rosado

Abstract Material flow accounting (MFA) can be applied to systematically quantify material inputs, outputs and throughputs to and from a geographical area, providing particularly relevant insights into managing resource flows and stocks, and identifying opportunities to close material cycles, moving from a linear to a circular economy. Remarkable advances in recent years have been made on the application of MFA to regions and cities, in particular going beyond material to product flows and providing increased details on life-cycle stages of products across these flows, which are crucial to estimate, understand and manage their associated environmental impacts. This chapter presents an MFA model of the Autonomous Province of Trento (Trentino) in northern Italy, and of the province's capital city Trento. The main purpose is to establish a model to estimate direct material inputs (DMI) and domestic material consumption (DMC) in thousand tonnes per year (reference year 2019), relying on publicly available online data on domestic resource extraction, industrial production, trade, freight transportation and waste generation. The DMC was 12.8 and 13.5 tonnes per capita in the province and in Trento, respectively; the result is below the EU mean of 14.2, but significantly higher than the reported DMC for Italy in the same year of 8.3 tonnes per capita. Accounting and characterizing resource flows associated with urban areas and regions is crucial to increase resource efficiency and mitigate environmental impacts at local, regional and global levels. Advanced detailed MFA models at city and regional levels can inform and support environmentally sustainable planning and policymaking.

Keywords Urban metabolism · Material flow analysis · Region · Material consumption · Product flows

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1 Introduction

1.1 Goal and Scope

Material flow accounting (MFA) can be applied to systematically quantify material inputs, outputs and throughputs to and from a geographical area, providing particularly relevant insights into managing resource flows and stocks, and identifying opportunities to close material cycles, moving from a linear to a circular economy. This chapter presents a regional MFA model of the Autonomous Province of Trento (Trentino) in northern Italy, and of its capital city—Trento. The main purpose is to estimate the annual direct material inputs (DMI) and domestic material consumption (DMC), relying on publicly available online data. Key results include the accounting and characterization of material and product flows going into and out of the regional economy, and of the overall consumption at city and regional level, by type of product.

2 Background

Cities have more than half of the world's population and contribute to about 80% of global economic output, concentrating trade, business, innovation and skills [1]. They are associated with 60–80% of global resource requirements, energy use and anthropogenic greenhouse gas (GHG) emissions [2, 3]. Despite the global and local sustainability challenges associated with increasing urbanization, the concentration of population and economic activities in cities also offers unique opportunities, and cities play a key role in climate change mitigation and sustainable development. The central role of cities in sustainable development is demonstrated by EU policies and the UN 2030 Agenda for Sustainable Development, including the Sustainable Development Goals (SDGs) [4]. Urban environmental sustainability is focused on Goal 11—Make cities and human settlements inclusive, safe, resilient and sustainable—and it directly contributes to a wide range of other SDGs [4].

Industrial ecology (IE) approaches and tools can help support the design, development and implementation of sustainable urban development strategies. These include, for example, urban metabolism (UM), material flow accounting (MFA) and life-cycle assessment (LCA). UM is widely supported as an approach to inform and support urban sustainability. In brief, the metabolism of cities entails visualizing a city as an organism or ecological system, and it addresses all socio-economic and environmental processes associated with urban activities. Such a system is composed of many interlinked subsystems and components (e.g., people, built environment, water, energy, waste, health, transportation) [1]. As such, UM can build on a system thinking perspective to provide a broader understanding of urban functions, needs, linkages across different domains, systems and processes, and identify hotspots and opportunities for improvement with an integrated perspective. System theory provides a systematic approach to system integration and to understand and predict changes within the system, and their implications [1, 2]. It can potentially address urban complexity, providing insight on the diversity and intensity of urban activities on a multiscale perspective (from urban blocks to neighbourhoods or cities). Within UM, a commonly used method is Material Flow Accounting (MFA), which considers the inputs and outputs of resources, emissions and waste [3].

2.1 Material Flow Accounts and Indicators

Physical accounting approaches are important to complement monetary approaches, which are often insufficient and provide limited understanding of the relationships between the economy and the environment. For over 20 years, the UN has called for the integration of environmental and economic accounting, to quantify services provided by natural capital as well as human-made capital. This is essential to characterize and manage the use and/or depletion of natural resources (in production to consumption chains) and the associated environmental implications [4]. Material flow accounting (MFA) can serve as a basis for environmental monitoring and for managing urban areas—accounting and characterizing material and product flows to evaluate their environmental impacts [5, p.12]. MFA relies on the principle of mass balance—total material inputs (entries) into a system equal total outputs plus the net accumulation within the system [5, p.12]. The principle of mass balance applies to the economy as a whole, but also to any of its subsystems (economy sectors, companies, etc.) [5, p.12].

Economy-wide material flow accounts (EW-MFA) are a statistical accounting framework applied at a national level in the EU to report material flows into and out of an economy in thousand tonnes per year. The general purpose of EW-MFA is to describe the physical interaction of a national economy with the natural environment and the rest of the world economy in terms of material flows (covering solid, gaseous, and liquid materials, except for bulk flows of water and air). In 2011, EU regulation No. 691/2011 implemented a legal obligation for EU Member States to report the EW-MFA to Eurostat; and in 2013, mandatory annual data collection and reporting started. Eurostat published a methodological guide for EW-MFA [6] and its derived indicators, including overall material flow balances and aggregated indicators on total resource requirements, resource efficiency and total domestic outflows to the environment. In 2012, the System of Environmental-Economic Accounting—Central Framework (SEEA–CF) was adopted as an international statistical standard by the UN [7], including a section on EW-MFA, which supports the need and appropriateness of MFA for accounting and reporting material flows.

2.2 The UMAn Model

UM and MFA can support a holistic, systematic and integrated analysis of complex systems and help to inform on resource use and efficiency. However, important limitations have prevented wider application to analyse urban areas, and to support decision-making towards sustainable urban development. For example, MFA has high data requirements, and it generally lacks insights on the environmental implications of material flows [8]—it does not account for upstream and downstream processes that occur beyond the city or system boundaries (e.g., extraction, production, transportation, end-of-life) [8]. Thus, increasing the level of detail of UM and MFA models could increase and improve their application. Further details, for example, on the specific use of materials are important to evaluate the potential environmental impacts associated with resource flows.

Remarkable research advances have been made by the Urban Metabolism Analyst (UMAn) model, which provides a methodological framework to account for material and product flows and stocks at regional and urban levels, building on the EW-MFA methodology [9]. The framework contributed to advancing UM research, by:

- Providing a systematic and harmonized MFA-based methodology, particularly suitable for EU regions and cities, as it builds on EW-MFA and on Eurostat standard statistical data for products (complemented with other datasets and sources);
- Assigning product composition to 28 harmonized material types, thus increasing the disaggregation/categorization level of material types; and
- Disaggregating data by economic sector and characterizing the life cycle phases of products, providing insight into the origin and destination of flows.

This paper presents a detailed MFA that applies the UMAn model to the Autonomous Province of Trento and its capital city.

2.3 Case Study: The Autonomous Province of Trento

The Autonomous Province of Trento is located in Northern Italy in the Alps (Fig. 1). In 2020, the population of the province was 542 166 [10], registering a 13% increase over the previous 20 years [11]. About 35% of the population lives in the province capital Trento. The province has a relatively high quality of life: GDP in 2020 was 37 120€/capita in the province, compared to a national GDP of 27 938€/capita [12]. The province is in the northern Italian Alps, in the Dolomites, characterized by a mountainous territorial morphology and the provincial economy relies strongly on the tourism and manufacturing sectors.

Fig. 1 Case study: the Autonomous Province of Trento in Italy

3 Materials and Methods

This section summarizes the materials and methods used in the MFA model, including sources, input datasets, and data analysis and processing. It is structured in four subsections, which draw on the four steps of EW-MFA: (3.1) System boundaries; (3.2) Data compilation and treatment; (3.3) Data analysis and classification by material type; and 3.4) Calculation of indicators.

3.1 System Boundaries

National, regional and urban MFAs can be characterized by two types of boundaries, which need to be clearly defined to ensure consistent accounting of material flows: one is the boundary between the economy and the natural environment (cross-border flows that consist of environment-economy inputs and outputs, such as domestic extraction); the other is the border with other economies (cross-border flows that consist, for example, of imports and exports) [5, p.22]. Borders with other economies usually correspond to geographical boundaries—often administrative units. The selection of geographical boundaries is particularly important since the model strongly depends on the type, quality and disaggregation of available data, generally collected for different administrative units.

In our model, geographical borders are considered to be the administrative borders of the Autonomous Province of Trento, which correspond to a NUTS3 territorial unit (code ITH20), and of the municipality of Trento, which corresponds to a local territorial unit (code 022205). Borders between the economy and the natural environment are associated with domestic extraction flows, namely: animal breeding and slaughtering, forestry activities (wood harvesting), fishing and aquaculture, the production of milk, milk products and eggs, mining and quarrying.

3.2 Data Compilation and Treatment

Data used in the model to calculate and characterize material and product flows were collected using 2019 as the reference year (the most recent year before the COVID-19 crisis in Italy), and compiled into: main tables, correspondence tables and support tables, as described below.

- **Main tables**

These tables have statistical data on material flows. Four main tables were compiled: Domestic Extraction, International Trade, Transport of Goods and Industrial Production.

Domestic Extraction—the domestic extraction table compiles data from seven sectors or groups: (a) mining and quarrying, (b) agricultural production, (c) wood harvesting (forestry), (d) fishing and aquaculture, (e) meat, (f) milk products, and (g) eggs. This came from a range of national and regional datasets on extraction and primary production. When data at regional/provincial level was not available it was allocated based on the number of employees in the respective sector. Data were collected from the national and regional statistics office databases, ISTAT and ISPAT, respectively [12, 13], and compiled according to the Combined Nomenclature (CN) classification system, which is the main classification for the European international trade in goods statistics used by Eurostat. Data were collected for Italy, the Autonomous Province of Trento and the city of Trento.

International Trade—international trade is reported at national level with CN structure—an allocation had to be done on the volume of international imports that go to the modelled region and that of international imports that go to rest of the country (ROC), and the same applied to international exports (disaggregating them into exports from the province and from the ROC). To do this, international trade data were combined with data on economic sectors of the destination of imports and the origin of exports, and with data on the significance of economic sectors in the province and in the ROC (in terms of the number of employees per economic sector).

Inter-regional Trade—to apply MFA to regions and cities we need to account for national imports and exports, i.e., flows from the ROC to the modelled region, and from the modelled region to the ROC. The model used national annual road freight transport by region of loading and unloading and by groups of goods from Eurostat, structured with the Standard Goods Classification [14]. The Standard Goods Classification for Transport Statistics (NST2007) provides statistical information about flows of products between NUTS2 units, based on their economic activity of origin. It is available for four modes of transport: road; rail; air; and water. Rail was assumed to account for 26% of the overall inter-regional trade based on a report on the transport of goods across the Brennero axis [15]. Water and air transport were excluded, due to the specificities of the region (no seaports or major airports exist in the province).

Industrial Production—data on manufactured goods by industry sector were used to model product transformation, i.e., the processing of raw materials and intermediate products into final products for consumption. Industrial production data are available at a national level [13], in ProdCom NACE Rev 2 categories. Harmonization was needed on several product units to convert non mass units into mass (in tonnes), which was based on the Eurostat Conversion Factors Table (with information on the average weight of several Combined Nomenclature Codes that are not accounted for in mass weight). For products that were not in the Eurostat conversion factors table, conversion factors were selected from literature (bibliographic and desk research). Data were collected for Italy, the Autonomous Province of Trento and the city of Trento.

- **Correspondence tables**

These tables have correspondences across classification systems and they build mostly on the Reference and Management of Nomenclatures system of Eurostat, RAMON.

CN to CPA and NACE—this table provides the correspondence between CN and EU Classification of Products by Activity (CPA) codes and Statistical Classification of Economic Activities (NACE), made available by Eurostat. The CPA follows the production origin criterion, i.e., products are grouped according to the economic activity of origin.

NST to CN—national and international transport data are available in different disaggregation levels and nomenclatures. The most common is the Standard Goods Classification for transport statistics (NST or NSTR, depending on the year), which is linked in this table to the CN structure.

CN correspondences—the database developed to support the UMAn model was built according to a CN2007 structure. Thus, a correspondence table between CN2019 and CN2007 was built, based on the changes reported by Eurostat.

- **Support tables**

These tables draw on ISTAT data [13], and they were mostly used to support extrapolations when provincial or municipality-specific data was not available.

Employees—the number of employees by NACE sector by municipality was considered from ISTAT data on enterprises—the number of people employed in local units of active enterprises (annual average values) in 2019. The number of employees in domestic extraction sectors was added.

Residents—the number of residents by municipality, to allocate goods for final household consumption in the city of Trento.

- **UMAn model plugins**

Plugins previously developed for the UMAn model [5] were used to (i) characterize material composition, (ii) estimate additions to stock (by identifying products with average lifespan longer than 1 year); and (iii) separate final and intermediate products in input flows.

3.3 Data Analysis and Classification by Material Type

With the data collected and treated as described, we (i) calculated domestic material inputs to the region (domestic extraction + imports) and estimated overall available resources (preliminary balance); (ii) characterized available resources in terms of life-cycle stage, i.e., splitting them into intermediate and final products; (iii) modelled product transformation in the region (transformation of intermediate products into final products, for consumption in economic sectors or final household consumption); and (iv) calculated domestic material consumption. As mentioned, classification of products by predominant material type (into 28 material types) used a UMAn model plugin [5].

3.4 Calculation of Indicators

With domestic extraction (DE) and imports to the region, we calculated the direct material input (DMI), as described in Eq. (1). Then, the transformation of intermediate products into final products was modelled, based on industrial production data. Domestic material consumption (DMC) was then calculated with final products (DMI_f) (which excluded waste generated in product transformation) and exports, as described in Eq. (2). Lastly, to downscale DMC to the provincial capital Trento, the "Use table" of CPA products by NACE sector was considered (for service sectors using predominantly final products): the relative share of employees by NACE sector in the municipality of Trento and in the province; and the share of residents in the case of using CPA products for final consumption (by households, social support organizations and public administration).

$$DE + Imports = DMI \tag{1}$$

$$DMI_f - Exports = DMC \tag{2}$$

4 Results and Discussion

In this section, we summarize the key results of the MFA model applied to the Autonomous Province of Trento, including domestic material inputs (DMI) and domestic material consumption (DMC) in 2019.

4.1 Available Resources

Figure 2 illustrates the available resources modelled by CN section, including domestic extraction, national and international imports, and national and international exports. These represent the inputs and outputs considered in the model, and are the modelling results with the lowest level of uncertainty, before significant extrapolations were made on product transformation. Most flows were associated with inter-regional trade: only 6 and 9% of overall exports and imports were international, respectively. Section V on Mineral products, was significant in all types of flows, except for international exports: it accounted for 66% of domestic extraction, 27% of national imports, and 25% of national exports. Two other sections were particularly relevant: section IX on Wood and articles of wood, and section X on Pulp of wood and paper products. The first accounted for 13–19% of all types of flows; while the second accounted for 9–18% of imports and 6–13% of exports (no domestic extraction). Lastly, exports were always lower than the respective imports—national and international—however, in international trade exports were 62% lower, while in national trade only 4%.

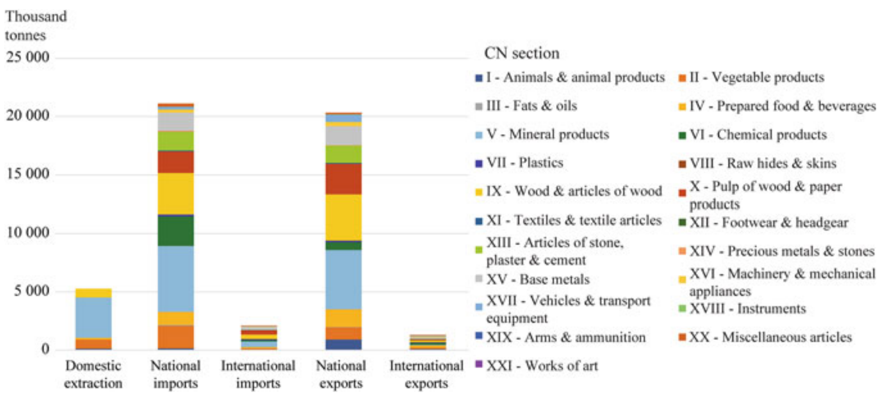

Fig. 2 Available resources by combined nomenclature (CN) section

4.2 *Direct Material Inputs*

Direct material inputs (DMI) to the province in 2019 were 28 500 thousand tonnes, 49% of which were final products. Figure 3 shows the product composition of inputs for final and intermediate products by CN section. Three CN sections were particularly relevant in both types of inputs—intermediate and final products: II on Vegetable products (these accounted for 8% of intermediate products and 12% of final products); V on Mineral products (31–37%) and IX on Wood and articles of wood (14–18%). Sections IV, VI, and XIII had significant inputs that entered the province mostly as final products corresponding to Prepared food and vegetables, Chemical products and Articles of stone, plaster and cement, respectively. These CN sections accounted for 8, 14, and 9% of the final product inputs, respectively. Lastly, two sections had significant inputs that consisted primarily of intermediate products, for processing/transformation in the province: X on Pulp of wood and paper products, and XV on Base metals, accounting for 13 and 10% of the intermediate product inputs, respectively.

Figure 4 shows the material composition of direct material inputs (DMI), for 28 types of materials. Non-metallic minerals and biomass accounted for over 77% of the DMI. This is closely linked with the results observed in the preliminary material balance, where sections V, IX, and X on Mineral products, Wood products, and Wood pulp and paper products were particularly significant. Within non-metallic mineral products, inputs were mostly composed of stone and sand; while in biomass wood and biofuels, agricultural biomass, and paper accounted for most inputs.

In the step of product transformation from intermediate to final products, about 364 thousand tonnes of waste were generated. It is important to highlight, however, that any other waste generated in the region stayed in our modelled DMC (final consumption), such as household waste and waste from construction activities, which are expected to account for the large majority of generated waste.

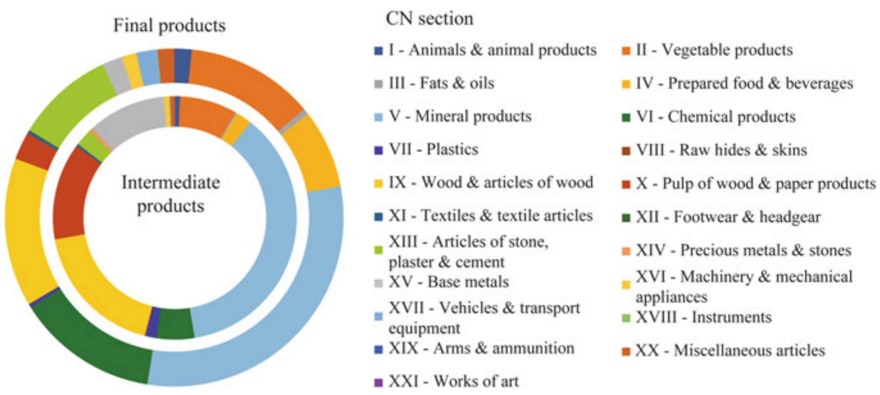

Fig. 3 Composition of direct material inputs (DMI) by CN section: intermediate and final products

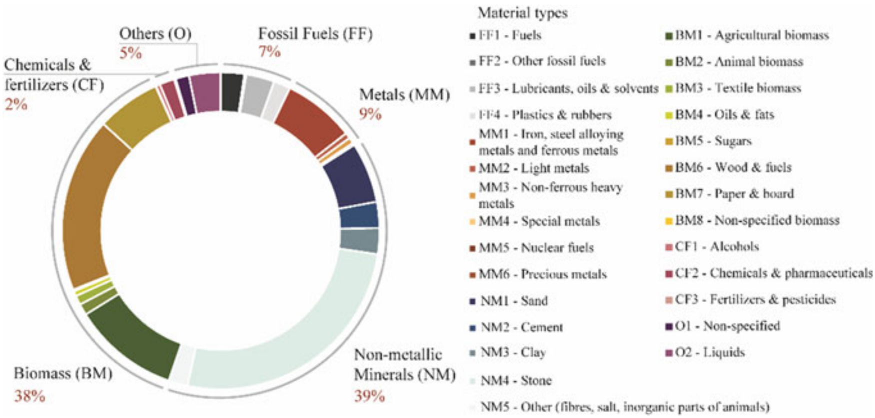

Fig. 4 Material composition of direct material inputs (DMI)

Table 1 Domestic material consumption (DMC)

	APT	Trento
Overall DMC (tonnes)	6 941 796	1 620 013
Population (source: [13])	543 721	119 616
DMC per capita (tonnes/capita)	12.77	13.54

APT—Autonomous Province of Trento

4.3 Domestic Material Consumption

Table 1 presents domestic material consumption (DMC), and Fig. 5 shows DMC distribution by CN section in the Autonomous Province of Trento and its capital city Trento. The overall DMC was 12.8 and 13.5 t/capita in the province and in Trento, respectively; the result is below the EU mean of 14.2, but significantly higher than the reported DMC for Italy in the same year of 8.3 t/capita [14].

The overall DMC per capita results were relatively similar in the province and in Trento. In 2019, Trento was home to 22% of the province's population; the DMC across CN sections varied between 20% in section XIII and 34% in section XVIII, which correspond to Articles of stone, plaster and cement, and Instruments, respectively.

5 Concluding Remarks

This paper presents an MFA model of the Autonomous Province of Trento and the provincial capital Trento. Its main purpose was to establish a model to estimate direct material inputs (DMI) and domestic material consumption (DMC) in thousand tonnes

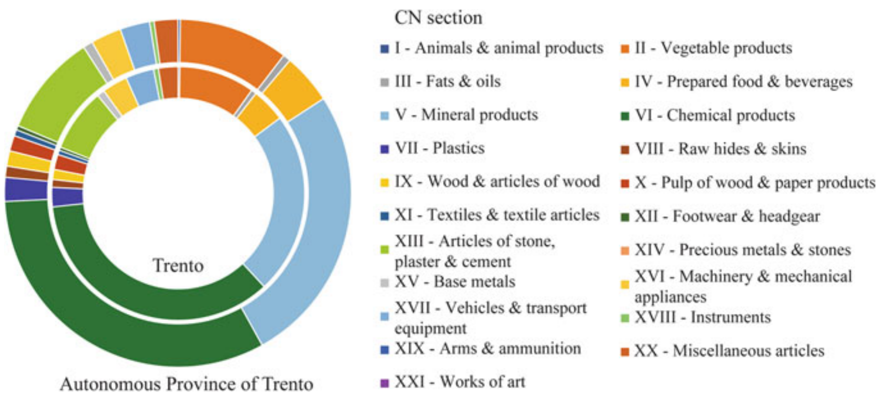

Fig. 5 Domestic material consumption (DMC) in the autonomous province of Trento (outer circle) and in the city of Trento (inner circle), for 2019

per year relying on publicly available online data on domestic resource extraction, industrial production, trade, freight transportation, and waste generation. The DMI in the Province was 28 500 thousand tonnes. The DMC was 12.8 and 13.5 t/capita in the province and in Trento, respectively; both results are below the EU mean of 14.2, but significantly higher than the reported DMC for Italy in the same year of 8.3 t/capita.

Accounting and characterizing resource flows associated with urban areas and regions is crucial to increase resource efficiency and to mitigate environmental impacts on a local, regional, and global scale. Advanced detailed MFA models at city and regional levels can inform and support environmentally sustainable planning and policymaking.

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References

1. Kutty AA, Abdella GM, Kucukvar M, Onat NC, Bulu M (2020) A system thinking approach for harmonizing smart and sustainable city initiatives with United Nations sustainable development goals. Sustain Dev 28:1347–1365. https://doi.org/10.1002/sd.2088
2. Shmelev SE, Shmeleva IA (2018) Global urban sustainability assessment: A multidimensional approach. Sustain Dev 26:904–920. https://doi.org/10.1002/sd.1887
3. Albino V, Berardi U, Dangelico RM (2015) Smart cities: Definitions, dimensions, performance, and initiatives. J Urban Technol 22:3–21. https://doi.org/10.1080/10630732.2014.942092
4. United Nations (2000) Integrated Environmental and Economic Accounting: An Operational Manual. New York

5. Rosado L (2012) A Standard Model For Urban Metabolism: Accounting material flows in Metropolitan Areas. PhD thesis. Lisbon: Universidade Técnica de Lisboa, Instituto Superior Técnico
6. Eurostat (2001) Economy-wide material flow accounts and derived indicators
7. United Nations (2014) System of Environmental—Economic accounting 2012—Central Framework. New York
8. Shahrokni H, Lazarevic D, Brandt N (2015) Smart urban metabolism: Towards a Real-Time understanding of the energy and material flows of a city and its citizens. J Urban Technol 22:65–86. https://doi.org/10.1080/10630732.2014.954899
9. Rosado L, Niza S, Ferrão P (2014) A Material Flow Accounting Case Study of the Lisbon Metropolitan Area using the Urban Metabolism Analyst Model. J Ind Ecol 18:84–101. https://doi.org/10.1111/jiec.12083
10. ISTAT (2022) Il Censimento permanente della popolazione in Trentino. Anno 2020. ISTAT. 12 May 2022. Available on: www.istat.it.
11. ISPAT (2001) La popolazione trentina nell' anno 2000. Servizio Statistica della Provincia Autonoma di Trento. December 2001. Available on: http://www.statistica.provincia.tn.it/.
12. ISPAT Servizio Statistica, https://statweb.provincia.tn.it/, last accessed 2023/02/02.
13. ISTAT. I.Stat, http://dati.istat.it/, last accessed 2023/01/31.
14. Eurostat. Eurostat database, https://ec.europa.eu/eurostat/web/main/data/database, last accessed 2023/01/31.
15. Cavallaro F, Corradini P, Sommacal G (2019) Project Report SMARTLOGI D4.2.5: Studio di fattibilità per migliorare il trasporto multimodale lungo l'asse del Brennero. Eurac Research. SMARTLOGI Project, funded by the European Regional Development Fund. Eurac Research.

Energy Communities: The Opportunity for an Energy Transition Characterized by a Return to the Territory

Monica Bolognesi

Abstract The creation of energy communities represents an opportunity to overcome the traditional social acceptance paradigm and sector approach in the energy field. The case study of an energy community in the making in the Alpine region enables experimentation with a territorial and heritage approach to the energy transition. This research project tries to connect together territorial heritage, renewable energy sources, and the local community dimension, identified as a strategic field of action also by European directives on energy. The method of analyzing local heritage energy resources and their contribution to energy mix composition, as well as conducting interviews to identify potential stakeholders to involve in setting up the energy community, reveals the presence of untapped potential, both from energy and social capital perspectives. The enhancement of local energy potential, respecting the concept of limitation in resource use and consistent with the protection of territorial, environmental, and landscape heritage, shows the return to the territory in energy production as a sustainable energy transition perspective.

Keywords Energy community · Territorial heritage · Energy sovereignty · Sustainability · Energy transition

1 Introduction

This paper considers the issue of the necessary transition to a development model marked by sustainability from a territorial and heritage-led perspective, that is, by focusing on the territory and on its complexity and multidimensionality, which also includes its energy dimension. The scope is the local community, also identified by European energy directives as a strategic field of action.

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This paper's ultimate contribution is to propose the construction of a sustainable energy model on a local scale starting from an analysis of energy heritage resources and their potential combined with the enhancement of social innovation forms found in the local community. Renewable energy communities (RECs) are an effective way to facilitate the return of energy production to the territory, as opposed to a traditional deterritorialized, fossil-based, extra-local energy production model.

The experimental case study presented here concerns an energy community-building process in Tirano, Lombardy, but the analysis of energy heritage has been extended to the entire broad area of Media Valtellina, to get a better understanding of the interactions between the different components in the territory. This research shows that it is possible to increase energy production from renewable energy sources (RES), especially for photovoltaics, by applying an energy production model based on the enhancement of local heritage. Moreover, in a context where local community activism is mainly manifested in the sphere of volunteerism with no particular focus on environmental issues, there are important social innovation initiatives related to the enhancement of territorial heritage identity elements that can be drivers in energy community-making.

This paper is structured as follows. Section 2 frames the paper within the territorialist approach and scientific production on the topic of energy communities; Sect. 3 describes the mixed methodology, which combines territorial analysis and surveys through interviews with local stakeholders, Sect. 4 reports the energy assets of the study area and the RES mix that can be activated in addition to the main results of the survey conducted through the interviews, which are then commented in Sect. 5.

2 Literature Review

The vision of the energy transition expressed in this paper is within the scientific approach of the territorialist school, based on the consideration of territory as a highly complex living organism and of territorial heritage as the set of environmental, urban, rural, infrastructural and landscape elements, assets and systems, shaped by the long-lasting coevolutionary process between human settlement and environment (Magnaghi 2020). Territorial heritage elements have an intrinsic *existence value*, related to long-lasting identity, and a *use value*, related to the activation of heritage resources and their use and management (Poli 2015), including in the energy field. Territorial heritage thus has a dual significance:

- some of its elements can take on energy values (e.g., agroforestry structures, water mills, canals…);
- it provides the coherence framework within which to evaluate land transformation (e.g., in the production of energy from RES, the protection of rural landscapes or historical settlement types must be ensured).

The energy patrimonialization process (Magnaghi and Sala 2013; Bolognesi 2018), defined as the identification and use of whole territory resources for energy production (because each territory expresses an energy potential that changes concerning the specific places peculiarities, Scudo et al. 2011), is essentially based on two aspects:

- overcoming a sectoral and functional approach to energy planning aimed at maximizing resource productivity according to a logic of predatory exploitation (Puttilli 2014), in order to propose an integrated, widespread, locally defined energy mix of various sources consistent with territorial heritage;
- overcoming a top-down approach in energy planning and management forms (Magnani and Patrucco 2018).

The inadequacy of RES social acceptance approach in territories is widely discussed in literature (e.g., Woolsink 2010; Devine–Wright 2011): it is important to foster local community participation, even in the energy field, with local stakeholders taking an active part in the process aimed at promoting sustainable and durable local development projects. Experiences of renewable energy communities (REC) are emerging and several studies give a definition of the term (Walker and Devine-Wright 2008; Seyfang et al. 2013; Tricarico 2015; Magnani and Patrucco 2018) and attempt clustering (Candelise and Ruggieri 2019; Moroni et al. 2019; De Vidovich et al. 2021). This paper focuses on the fundamental return to the territory in energy production, a strategy that combines local energy resource enhancement with a renewed prominence of local stakeholders; energy communities can be an effective experiment for this energy transition strategy.

3 Methods

3.1 The Application of the Energy Patrimonialization Model

The mixed methodology by which the energy patrimonialization model has been applied to the case study consists of several steps described below.

- *Identification and cartographic representation of energy heritage* (both natural and territorial resources), based on data from land-use mapping, regional technical maps, and national atlases on energy resources.
- *Analysis of the energy heritage and definition of a specific RES mix*. Different resources required different methodologies. To estimate photovoltaic potential, for example, the r.sun function of Grass-Qgis (combining clivometry and slope exposure data) made it possible to obtain a grid of solar radiation per unit area (measured in kWh/m^2). It was thus possible to associate solar radiation values with available roof areas (net of historical heritage buildings) and photovoltaic panel performance to obtain the amount of energy that can be produced. For forest biomass energy potential, Corine Land Cover has been used as starting data. Growth rate (m^3/ha per year) and density value (kg/m^3) were associated with each polygon classified by forest type (parameters drawn from Bernetti et al.

2009, Fagarazzi and Tirinnanzi 2015), to estimate forest regeneration capacity and, on this, calculate the percentage of residue from other wood processing, useful for energy production. Further development of hydropower would require a specific study on hydro-energy potential which is not addressed in this research.
– *Analysis of the relationship between local stakeholders and energy heritage* to investigate the activism of local stakeholders in the energy sector and local development, the degree of participation and involvement of local populations and institutions, and the existence of conflicts on a local scale, with the exploration of social practices directly or indirectly involving the use of energy heritage. Seven semi-structured interviews with local stakeholders were carried out with snowball sampling, partly remotely and partly face-to-face, between June and September 2021. Interviewees include two members of local government, an expert on development dynamics venues, a cultural operator, two economic operators, and a member of the non-profit sector.

3.2 The Case Study of Tirano

Tirano is located in the borderland on the northern edge of Lombardy in the middle of Media Valtellina Valley, which constitutes the regional frame of reference for reorganizing the energy production and consumption system.

The Renewable Communities Report 2022 (Legambiente 2022) cites Tirano among the "100% Renewable Municipalities" for the important contribution of local and distributed renewable sources in covering local energy needs and the Alpine Energy Community of Tirano (SO) as an example of REC in the making.

The energy community arises in a context that benefits from a district heating plant with a 33 km network and 789 users reached with the service (Bonifazi et al. 2022), which can already rely on an energy self-generation system that meets about 50% of local community needs (Coletta et al. 2020). The Tirano district heating plant operated by the TCVVV Company (Teleriscaldamento Cogenerazione Valtellina-Valchiavenna-Valcamonica) began operating in 2000; it was started by public financing and a widespread partnership of small local shareholders on which REC's community-engagement path is built on. Thus, the development of an energy community can therefore be the driving factor for increasing energy production from RES.

Open access cartographic data for Media Valtellina Valley (land use, elevation grid, technical cartography) were sourced from the Lombardy Region cartographic portal. Data on average wind speed came from the RSE Wind Atlas. Data on RES plants already in operation can be found on the GSE Atlaimpianti portal.

4 Results

4.1 Identification and Cartographic Representation of Energy Heritage

Media Valtellina has a rather articulated structure and a rich heritage value endowment to be conserved and enhanced; protection of high environmental and landscape value elements has been formalized by establishing Sites of Community Interest, parks, and special conservation areas. Territorial heritage includes, for example, the hydrographic network of the River Adda and its tributaries, elements related to the agro-sylvo-pastoral economy (forests, pastures, *maggenghi*, cultivations, terraces), historical settlement structures, and ancient systems of hydraulic energy exploitation.

Energy production aimed at enhancing local resources and involving the whole territory in composing a locally defined RES mix must interact virtuously with environmental and landscape heritage elements and must prevent criticalities in the traditional centralized energy production model. Cartographic selection and composition in a map (with the Qgis software) of potentially energy-usable elements contained in land use or maps of average wind speed is the first step to define the endogenous energy potential of the territory.

The map in Fig. 1 depicts heritage resources theoretically available for energy production in the whole of Media Valtellina and in detail in the Municipality of Tirano, namely:

- urbanized areas and building roofs. The most significant contribution to energy production is expected to come from the recent expansion of built-up areas and productive/commercial areas of main centers;
- areas with an average wind speed greater than 4 m/s, mostly localized close to mountain peaks;
- forests, important ecological-environmental and landscape resources but also energy resources: residues from silvicultural activities and waste resulting from wood processing can contribute to energy production from RES;
- tree crops, a typical feature of Valtellina both on the plain (apple orchards) and the Rhaetian side of the valley in terraced vineyards: pruning clippings can contribute to biomass energy production;
- the catchment area of the River Adda and its tributaries, with numerous hydroelectric power plants for energy production and ancient watermills in some cases is already undergoing redevelopment and refunctionalization.

The map, therefore, includes elements belonging to the territorial heritage that can be enhanced for energy purposes such as old mills, forests with silvicultural residues or vineyards and orchards with pruning clippings, as well as elements that are part of the settlement system which are not part of the territorial heritage, e.g., recent building roofs.

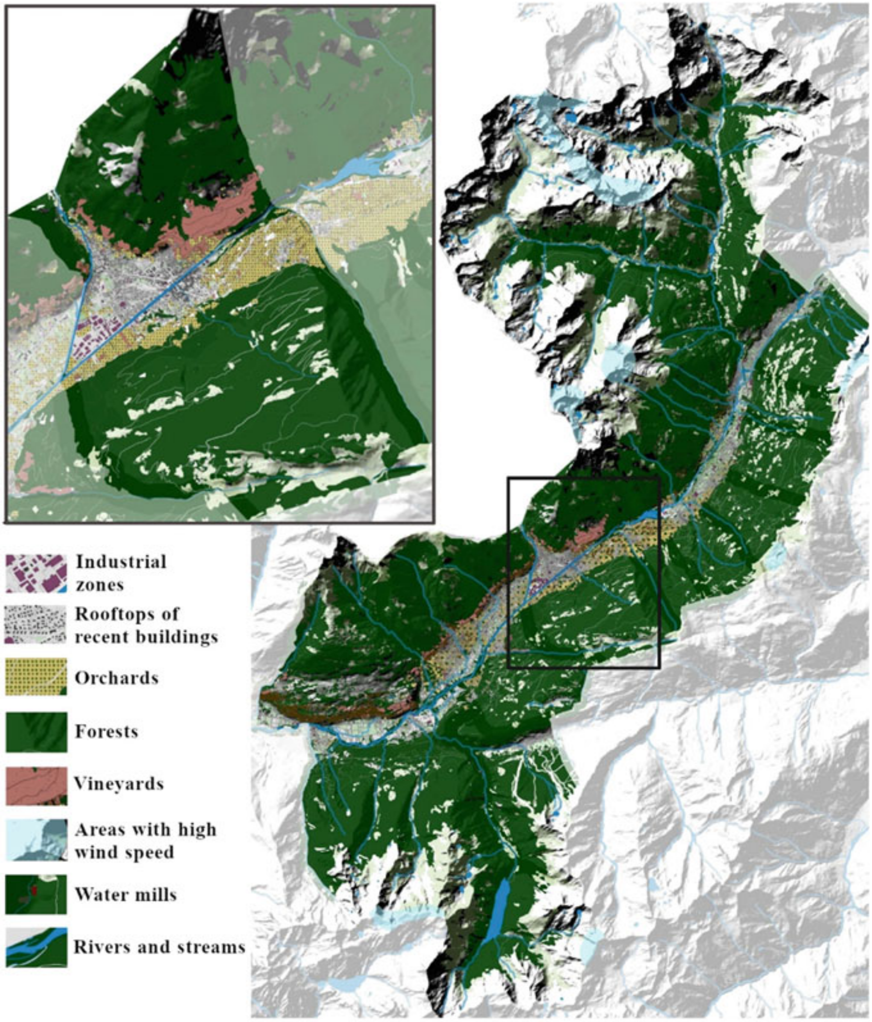

Fig. 1 Theoretical availability of renewable energy sources in Media Valtellina and the Municipality of Tirano (boxed area). Processed using the Qgis software

4.2 Analysis of the Energy Heritage Potential and Definition of a Specific RES Mix

The analysis of the availability of renewable sources yields a set of potential energy resources in the study area. A plurality of renewable sources contributes to the composition of the Tirano energy mix (Table 1): biomass from pruning and forestry, solar PV, and hydroelectric (for wind power, in suitable landscape areas the average wind speed is not high enough, so this RES has not been included in the mix).

Table 1 The energy mix in Tirano

Renewable energy sources		Current production from RES	Potential energy contribution to the mix
Biomass	From forestry residues	50.9 thermal GWh 3.3 electrical GWh produced by the TCVVV plant in Tirano[a]	33.66 GWh/year (Media Valtellina) 4.4 GWh/year (Municipality of Tirano)
	From pruning tree crops (vineyards and orchards)		7.1 GWh/year (Media Valtellina) 1.6 GWh/year (Municipality of Tirano)
Solar PV		3.8 GWh/year (Municipality of Tirano)[b]	30.6 GWh/year (Municipality of Tirano)
Hydroelectric and mini-hydroelectric		One hydroelectric plant with a nominal capacity of 85 kW in Tirano[c] There are also large-scale plants in other municipalities in Media Valtellina	Additional producible energy requires a specific technical study of Hydro-energetic potential

[a]FIPER report 2021. The amount of biomass from forests in the territory of Tirano Valley municipalities compared to the total is unknown
[b]Estimate made from Atlaimpianti data that reports a total of 3436 kW nominal power of currently installed plants, considering an average producibility of 1100 kWh per installed kW
[c]Atlaimpianti GSE source

Energy production has to be consistent with territorial heritage. Energy patrimonialization process effectiveness should therefore be assessed about hydro-geomorphological and ecosystem balances that underlie the bioregion functioning. The energy production value of local heritage elements has to take into account the other functions (regulatory, support, cultural…) that the same assets can provide for the territory, and the various "interferences" among functions require a use priorities assessment. The analysis of individual RES energy potential, aimed at identifying the local energy mix best composition, used parameters diversified by source to define resource availability and the compatibility of use with territorial heritage protection and regeneration. For example, research identified land consumption as a key factor in determining the impact of energy production facilities, due to the importance of reserving its use for agricultural functions and preserving it from artificial cover: therefore, places in urbanized areas are favored and certain land use categories have been excluded from possible plant installation. After developing a solar radiation map of the whole territory (as described in the method section), available building roofs were identified, after excluding those already occupied by photovoltaic panels (Atlaimpianti GSE) as well as the historical building heritage to be protected. No ground-mounted PV installations were planned in order to prevent any land consumption. The roof area to be used for photovoltaic panels' installation was conservatively estimated as 1/3 of the roofing projection on the horizontal plane

(Scudo 2013). Therefore, potentially obtainable energy was estimated by summing the potential of each rooftop classified as suitable. The PV energy potential for Tirano is estimated to be about 30.6 GWh per year.

In terms of forest biomass, its energy potential was calculated taking care not to exceed the forest annual regeneration capacity and considering only the residual biomass fraction of other wood processing to be used for energy production. Areas unsuitable for biomass harvesting such as protected areas or forests lying on very steep terrain have been also subtracted from the total forest area. On the remaining forested areas, as per the Corine Land Cover classification, an algorithm is applied to individual polygons that relate to the area, annual growth rate by species, density, and the woody residue percentage to obtain the amount of biomass available (Bernetti et al. 2009), quantified in Media Valtellina as about 9900 t/year. Considering a heating value of 3.4 MWh/t (Fagarazzi and Tirinnanzi 2015), therefore, about 33.66 GWh of energy can be produced (in the Municipality of Tirano about 1294 t/year of forest biomass for 4.4 GWh of energy).

To estimate the energy potential of tree crop pruning biomass, the 2018 land use entries "vineyards" and "orchards" are used as references. Assuming the productivity of pruning biomass per hectare of 2 tons, with a heating value of 2.3 MWh/t, it is estimated that tree crop pruning biomass can produce about 7.1 GWh of energy per year in the whole of Media Valtellina (1.6 GWh in the Municipality of Tirano).

The current mix of energy production from RES, based essentially on biomass feeding Tirano district heating plant and hydroelectric plants, even large ones, can be implemented by focusing on the spread of photovoltaics on buildings roofs (currently underdeveloped) and the use of forest biomass linked to a local dimension and less dependent on bioregion for raw material supply. Recovery activities of abandoned local heritage elements, for example, chestnut groves, can also have the side effect of increasing the availability of raw materials to be exploited for energy production.

4.3 *Analysis of the Relationship Between Local Stakeholders and Energy Heritage*

Another part of this research focused on the interplay between heritage and the local community to investigate the level of community involvement in local heritage enhancement (Table 2) by conducting semi-structured interviews with local stakeholders. Research showed a fair social mobilization of activities that need to be connected through the socio-productive institutes of energy communities. The analysis of the relationship between heritage and local community revealed the local figures that could be involved in the creation of a multi-sectoral and multi-person energy community in Tirano: local institutions, third-sector cooperatives, associations, businesses, farmers, property or land owners, and citizens willing to participate as protagonists in the energy transition.

The main critical issues that emerged from the interviews are summarized below:

Table 2 Assessment indicators on the community-heritage relationship

Level of community involvement in local heritage enhancement	Presence and types of "bottom-up" forms of planning and covenants (local neo-agriculture supply chains, multifunctional agricultural parks, river–lake-mountain-landscape contracts, bio districts, food communities, eco museums, landscape observatories…)
	Presence and types of social self-organization forms and level of population involvement (ecovillages, cultural factories, active citizenship forums, committees and territorial aggregations of citizens, experiences of mountain repopulation and recovery of abandoned territories…)
	Presence and types of innovative forms of economy and productive institutions related to the self-valorization of common heritage assets (enterprises and networks of solidarity economies, social and community foundations, time banks, forms of mutual aid, local currencies, microcredit, circular economies, community cooperatives, experiences of energy self-production…)
	Conflict on a local scale

- difficulties for the forest/wood supply chain and the abandoned state of local forests (due largely to fragmentation among private individuals of forest ownership) which suggests that a large amount of biomass feeding the district heating plant is not strictly locally sourced;
- recent recapitalization of the district heating plant management company with the entry of Cogeninfra SpA Group, which acquired 71% of TCVVV shares and significantly reduced the "weight" of small local partners who started the project in the early 2000s;
- conflicting positions on Valtellina methanization process. Valtellina upstream of Villa di Tirano is currently a non-methanized area, and there is a plan to extend the methane gas network to the entire valley over time. Respondent positions are mixed; methane would clearly compete with the district heating system already in operation in Tirano, as well as potentially discouraging any investment in this technology in other municipalities, yet for some people it may be used in small villages not connected to the district heating and in industrial areas;
- concerns about the risks associated with the use of forest biomass for the impact on and reduction of biodiversity.

Examples of local stakeholder planning and activism in local development also emerged from the interviews:

- conversion to liquefied natural gas (LNG) of the vehicle fleet of a local logistics company, with the supply of liquid bio-methane from a zootechnical cooperative, a virtuous example of circular economy;
- terracing recovery projects implemented by public–private partnerships, leveraging European Structural and Investment Funds (ESI) and other resources made available by a banking foundation (Cariplo), which also promoted a local development strategy aimed at creating the cultural district of Valtellina;
- the presence of cultural heritage recovery and sustainability activities (Butega Valtellinese, Confraternita del chisciöl…);
- activities of the social cooperative "Il Gabbiano" for the reintegration of people in socially fragile conditions through agricultural work on otherwise abandoned land; the cooperative also plans to undertake activities in the forestry sector to collaborate with wood processors and energy producers.

5 Discussion

It is possible to implement Tirano's energy mix and increase local production from RES, particularly forest biomass and photovoltaics. Table 1 shows that the current production of energy from biomass is higher than what could be produced using only local forest residues according to sustainability criteria: this fact, combined with the poor exploitation of the local forest-wood supply chain (which emerged from the interviews) suggests that the material comes largely from outside Media Valtellina. Assuming, however, that 30% of raw materials come from within the territorial boundaries of the study area (thus well below the 70 km that define the short supply chain) as already currently used in the plants in operation, the use of the remainder can be assumed to increase local thermal energy production by about 50%.

Analysis revealed that there is great potential to increase electricity production from RES using existing building roofs for photovoltaic panel installation without any land consumption. In addition to the plants already present in the area, panels can be installed on a large number of surfaces, for a more than fivefold increase in electricity production from photovoltaics (estimated producible energy 30.6 GWh/year).

The issue of local supply chain development for energy production, a topic covered in all interviews with local stakeholders, brings out the contradiction with the methanization process that is starting in Tirano (following a debate lasting for years). The use of methane, a non-renewable energy source, is in obvious competition with the biomass district heating system already operating in the area and in contrast to the necessary decarbonization of the energy system. Perhaps an implementation of REC, enhancing local endogenous energy potential, can help overcome this contradiction.

Social innovation initiatives related to the enhancement of territorial heritage identity elements have grown in Tirano. Energy communities can develop from these innovation niches, and the local stakeholders involved can become part of the community that promote and manage self-sustainable local development processes.

The level of community involvement in local heritage enhancement can be assessed from practices put in place for socially recognized common care. The "Il Gabbiano" social cooperative offering job placement opportunities in agriculture (work in vineyards, orchards, and the cultivation of ancient varieties of wheat…) to fragile members of society in synergy with local economic activities is one of the figures set to play a key role within the energy community. It's an example of local development based on territorial milieu care and enhancement, in fact, this fruitful collaboration contributes to good practice preservation and reproduction as well as spreading awareness of the value of local identity elements.

The community-engagement pathway is the result of lasting cultural awareness action carried out to activate the widespread shareholder project in the district heating power plant building process (De Vidovich et al. 2021). Signs of territorial heritage self-recognition initiatives can be identified in some actions that institutional figures, associations, and citizens are carrying on in Tirano and throughout the regional context with public–private partnerships, for example the territorial cooperation project "Preserving and enhancing the cultural landscape of Media Valtellina" funded by Cariplo Foundation for work on terracing, or again the project for chestnut grove recovery by Ambiente Valtellina.

6 Conclusion

An energy community can be defined as a social cultural and economic organization that locally self-produces its energy needs by enhancing its own territorial resources while protecting its environmental and landscape common goods and thus reducing its ecological footprint (Bolognesi and Magnaghi 2020). It is a community that takes ownership of its common goods heritage and enhances it triggering self-sustainable local development models.

Processing a sustainable energy model in Tirano on a local scale, a REC still in the making but rich in heritage resources, represents an opportunity to experiment with a return to territory in energy production. The application of an energy patrimonialization model to the Tirano area has shown that RES production can significantly increase and that local stakeholders already involved in cooperation experiences can play an important role in energy community development.

Beyond the purpose of facilitating RES penetration throughout the country and bringing energy demand and production closer together, energy communities can provide opportunities to experiment with approaches that can combine land care with social capital enhancement, with positive spin-offs in terms of self-sustainable development and the creation of opportunities for the population (particularly for the empowerment of disadvantaged groups) and for peripheral territories (e.g., under the

National Strategy for Inner Areas). The use of still untapped local energy resources can produce a great increase in overall national energy production, necessary to achieve the goals set by international strategies for the energy transition and mitigate global warming.

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References

Bernetti I, Fagarazzi C, Sacchelli S, Ciampi C (2009) I comparti forestale e di prima trasformazione del legno, Arsia Regione Toscana

Bolognesi M, Magnaghi A (2020) Verso le comunità energetiche. Scienze del Territorio special issue Abitare i territori al tempo del covid 142–150. https://doi.org/10.13128/sdt-12330

Bolognesi M (2018) Per una politica energetica integrata con la valorizzazione del territorio: il caso della Valdera. In: Saragosa C, Rossi M (eds) Territori della contemporaneità. Percorsi di ricerca multidisciplinary. Florence University Press

Bonifazi A, Sala F, Bolognesi M (2022) Energy community innovations and regional policy diversification in Italy: a preliminary analysis. In: 2022 AEIT international annual conference (AEIT), pp. 1–6. https://doi.org/10.23919/AEIT56783.2022.9951853

Coletta G, Angelucci V, Bernardo N, Pellegrino L, Sala F, Zulianello M (2020) Comunità dell'Energia: analisi tecnica, energetica e ambientale dei progetti pilota. Periodic Report of Project 2.7 Modelli e strumenti per incrementare l'efficienza energetica nel ciclo di produzione, trasporto, distribuzione dell'elettricità. RSE, Milan

Devine-Wright P (eds) (2011) Renewable energy and the public. From NIMBY to Participation, Earthscan, London

Fagarazzi C, Tirinnanzi A (eds) (2015) Strumenti per lo sviluppo di filiere biomassa energia di qualità. In: Pacini (ed) Approcci operativi per garantire la sostenibilità ambientale e sociale, Pisa

FIPER (2021), Biomass district heating plant report

GSE, Atlaimpianti https://www.gse.it/dati-e-scenari/atlaimpianti

Legambiente (2022) Rapporto comunità rinnovabili

Lombardy Region, Geoportal https://www.geoportale.regione.lombardia.it/

Magnaghi A (2020) Il principio territoriale. Bollati Boringhieri, Milan

Magnaghi A, Sala F (2013) Il territorio fabbrica di energia. Wolters Kluwer Italia, Milan

Magnani N, Patrucco D (2018) Le cooperative energetiche rinnovabili in Italia: tensioni e opportunità in un contesto in trasformazione. In: Osti G, Pellizzoni L (eds) Energia e innovazione tra flussi globali e circuiti locali. EUT Edizioni Università di Trieste, Trieste

Moroni S, Alberti V, Antoniucci V, Bisello A (2019) Energy communities in the transition to a low-carbon future: a taxonomical approach and some policy dilemmas. J Environ Manage 236:45–53. https://doi.org/10.1016/j.jenvman.2019.01.095

Poli D (2015) Il patrimonio territoriale fra capitale e risorsa nei processi di patrimonializzazione proattiva.In: Meloni B (eds) Aree interne e progetti d'area. Rosenberg e Sellier, Turin, pp 123–140

Puttilli M (2014) Geografia delle fonti rinnovabili. Energia e territorio per una eco-ristrutturazione della società, Franco Angeli, Milan

RSE, Wind Power Atlas. https://atlanteeolico.rse-web.it/

Scudo G, Clementi M, Bertazzoni L, Vasino P, Garrone G, Soro F (2011) La sovranità energetica come coagente dello sviluppo locale: metodologia e caso studio. Il Progetto Sostenibile 29:36–43

Scudo G (2013) Tecnologie solari integrate nell'architettura. Processi strumenti sistemi componenti, Wolters Kluwer Italia, Milan

Tricarico L (2015) Energia come community asset e orizzonte di sviluppo per le imprese di comunità. Impresa sociale 5:53–64

De Vidovich L, Tricarico L, Zulianello M (2021) Community energy map. Una ricognizione delle prime esperienze di comunità energetiche rinnovabili. Franco Angeli, Milan

Walker G, Devine-Wright P (2008) Community renewable energy: What should it mean? Energy Policy 36:497–500

Woolsink M (2010) Contested environmental policy infrastructure: Socio-political acceptance of renewable energy, water, and waste facilities. Environ Impact Assess Rev 30(5):302–311. https://doi.org/10.1016/j.eiar.2010.01.001

Investment in Greening Last-Mile Logistics: A Case Study

Franco Corti and Alessandro Nava

Abstract Based on growing interest in sustainable solutions in last-mile logistics, one of the most promising investments is the electrification of commercial fleets to decrease the high level of pollution created by urban freight traffic. In this case study, vans that can be driven with a C1 European driving license are considered, mainly used in B2B deliveries to small shops and SMEs in city centres. The purpose of this research is to analyse the reasons behind the choice of switching the last-mile logistic service fleet to electric and its economic and environmental implications and to analyse the main barriers to its implementation. To do so, we use interviews from managers working in a successful Urban Consolidation Center (UCC) in Italy. The Italian energy infrastructure, the cost of electric vans, and the actual insufficient technological development of van batteries are the key issues highlighted in the interviews, but lower operating costs, lower fuel costs, a decrease in negative environmental externalities, possible institutional cooperation and better working conditions for couriers are the main features to consider in the switch to electric.

Keywords ESG · Case study · Last-mile logistics · UCC

1 Introduction

Today almost 56% of the world's population live in cities with an urbanization trend that is expected to continue and reach a point where nearly 7 of 10 people will live in cities by 2050 (The World Bank Group 2022). With more than 80% of

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global GDP generated in cities, urbanization can contribute to sustainable growth through increased productivity and innovation. This rapid growth is also influencing the increasing demand for freight delivery in urban contexts and also the level of e-commerce and traffic (Digiesi et al. 2017). This phenomenon has several consequences, for our purpose, one of the most critical is that 25% of total global Green House Gas (GHG) emissions are related to transportation, 75% of which comes from road transport (IEA 2021). Governments and private organizations are not neglecting the environmental and social consequences of urban transport and so they are trying to develop and implement measures, policies, and incentives to counteract the high level of pollution generated. The problem relates mostly to GHG emissions, but also noise and safety pollution are externalities that must be incorporated into the negative impact on society.

The Fit for 55 programme (European Commission 2021) is a package of measures that have been elaborated to provide policy instructions to support Member States in cutting emissions by at least 55% by 2030. This target is going to be addressed through several initiatives such as an increase in the number of electric vehicles (EVs) or ones powered by alternative fuels. To sustain this measure, the EU's aim is to install charging stations every 60 km on main roads: the purpose is to install them by 2025 for cars and by 2030 for trucks in urban areas too. There are several measures proposed by the EU Commission to contrast pollution relating to manufacturing and restrictions on combustion vehicles by 2035 to a future increase in fuel prices for freight transport.

Focusing on urban freight transportation, as proposed by the Fit for 55 programme, a possible solution could be the electrification of vehicles. In this case, commercial fleets could take advantage of the intrinsic characteristics of EVs to reduce the negative impact with lower GHG and noise emissions, and better conditions both for couriers and the local community. The role of companies that provide services in urban areas is crucial, since they manage the usage and circulation of means of transport to deliver goods to and from their warehouses and places of final delivery, controlling the modality and routing of the whole process (Patella et al. 2021).

Existing literature investigates the impact of last-mile logistics provided with light electric freight vehicles (LEFVs) belonging to N1 category according to EU vehicle classification, as bicycles, tricycles, or small vehicles under 3.5 tonnes (de Oliveira et al. 2017; Lebeau et al. 2013; Schau et al. 2015). In this case, we focus on medium-sized vehicles, which are electric vans belonging to the N2 category, exceeding 3.5 tonnes but not exceeding 12 tonnes, and which can be driven with a C1 European driving license, thus limiting this group to those that do not exceed 7.5 tonnes. It is common to study small-medium-sized parcel deliveries, such as those related to e-commerce deliveries and LEFVs, but larger ones, which are likewise needed by shops and Small-Medium Enterprises (SMEs) located in city centres and delivered through medium-sized vehicles, are often neglected. On the other side, this phenomenon is not so well known because last-mile logistic services have difficulties integrating EVs that do not exceed 7.5 tonnes in their fleets. Therefore, the main purpose of this research is to investigate the reasons that could incentivize companies to convert their fleets to electric beyond existing technical solutions and the purchase cost factor.

2 Related Literature

To have an outlook on this kind of service the starting point is to analyse the related literature on bicycles, tricycles, and LEFVs. The first and one of the most important problems of last-mile logistics is that it is the least efficient stage of the supply chain (Wang et al. 2016). Up to 28% of total delivery costs are imputable to the last mile and it is due to several aspects, starting from the high cost of organization to the extensive amount of time spent accomplishing it, compared to the other steps in the supply chain. Some studies pointed out that these aspects are attributable to different determinants, i.e., a fragmented and uncoordinated service, traffic volume and, finally, Urban Vehicle Access Regulations (UVARs) and Low Emission Zones (LEZs) in city centres and particular areas in the industrial side of the city (Digiesi et al. 2017).

Some authors demonstrated that congestion, lack of loading/unloading parking due to high-density populations, inefficient planning and logistics sprawl lead to longer distances to final receivers, and so increase the negative externalities that the last-mile logistic service produces and the related costs (Coulombel et al. 2018). Congestion is mainly due to the high volume of traffic and the lack of city design (i.e., unloading parking, ancient narrow streets, etc.). At the same time, congestion could be partially solved with the creation of Urban Consolidation Centres (UCC) and mid-delivery points, as illustrated by Janjevic and Winkenbach (2020) and Trott et al. (2021).

The conglomeration of different last-mile logistic services to reduce the total cost of delivery is addressed by literature but it is very difficult to apply because of competition between different operators and clients. However, a possible solution to this issue is to set up a neutral service, which operates on a coopetition scheme to complete the last step of delivery (Zou and Zhao 2010).

Focusing on clients, some researchers pointed out that small stores suffer from a lack of storage space, so they need continuous inventory replenishment (De Magalhães 2010; Boulaksil et al. 2014). In this case, daily service is necessary, but at the same time, it has a strong social and environmental impact (Digiesi et al. 2012).

In urban areas, road freight transportation is the prime culprit for negative externalities related to delivering goods: as previously mentioned, they range from environmental impact to economic and safety issues. To decrease the impact of this phenomenon, switching fleets to electric could be a possible solution. However, commercial EV purchase costs are three times higher than conventional diesel vans, but the operating costs of conventional ones are almost four times higher than EVs (Digiesi et al. 2012). Delivery vans are more cost-effective for deliveries weighing 20 kg or more, and freight tricycles are more cost-effective with short time intervals (Tipagornwong and Figliozzi 2014). Focusing on the supply of SMEs and small shops in city centres, we want to investigate the use of medium-sized vans that are also necessary to deliver heavy and large packages (i.e., the typical size considered is a pallet).

Table 1 Interviews

Current role	Education	Experience
Logistics manager and deputy general manager	M.Sc.	>15 years
Operations manager	High School	>15 years
IT manager	M.Sc.	10 years

3 Method

To answer our research question, we decided to conduct a case study. This method is commonly used to consider context variables to explain a particular phenomenon, without the use of data but by creating a theoretical sample of single sources to obtain the information (Yin 2017).

In this specific case, we conducted an exploratory case study of a last-mile logistic service (LMLS) in Italy provided by a third-party company to different logistic operators who choose this neutral service for the last part of the delivery process. The effects of investments in greening this service are multiple, at the same time, we want to consider the effect on the city too and how the company wants to integrate EVs into its fleet.

The information was obtained through semi-structured interviews performed both in person and via video calls, confirmed with documents and direct observations. The limited number of experts belongs to the individual successful company and is identified through convenience sampling (Etikan 2016) and a summary of the LMLS managers interviewed is summarized in Table 1.

In these interviews, the two main topics were understanding the integration and measures LMLS has adopted in city centres and the barriers and benefits of switching its fleet to electric.

4 Results

The results of the interviews highlight several suggestions, thanks both to the extensive experience of the managers and the long company history, especially since this LMLS already tried a pilot scheme with one EV more than 10 years ago and it was unsuccesful.

Seven key aspects arose as reported in Table 2 and have been divided according to three main categories of the barriers to implementing the service: operational, safety, and economic (Paddeu et al. 2018).

The "payload and size of the van" is a real issue because of the market's lack of electric vans that do not exceed 7.5 tonnes equipped with a hydraulic tail. In this way, it is very difficult for LMLS to deliver medium-heavy packages to SMEs and city centre shops because smaller means of transport do not have the required payload and characteristics. Also, different van producers are innovating their offer

Table 2 Data structure

Example of quotes	First-order codes	Second-order themes
"We are rethinking our fleet: a part of small-medium-sized deliveries could be managed with a few LEFVs, so we could easily introduce some of them. At the same time, we have a problem with medium-heavy deliveries and the related vehicles to fulfil the operations"	The van's payload and size	Operational
"Personally, we have a sufficient energy infrastructure, even if it only gives us the possibility for slow charging. It is not currently feasible to foresee a scenario in which entire company fleets or a large part of the city switch to EVs that need to charge during the night"	Lack of energy infrastructure	Operational—Safety
"With EV we will sustain cheaper ordinary maintenance, but the real problem will be dealing with mechanical emergencies"	Maintenance	Operational—economic
"Our drivers need to work in safe and functional conditions, not only from an operational point of view but also from a personal one: having a van without the possibility of air-conditioning is out of the question"	Working conditions	Operational—safety
"There are several monetary incentives to modernise fleets, not necessarily to electric: EV costs are decreasing, but they are still very high"	Purchase cost	Operational—economic
"We are interested in medium-heavy duty vans, but the offer has only recently started to become available and affordable: the technological offer is rapidly changing, and it is tricky to predict which would be the best one"	Technological development	Safety
"A key issue is the constant high volatility on the electric market in terms of prices"	Energy costs	Economic

but the required applications (hydraulic tail, high durability batteries, etc.) use a lot of energy to operate and require more research and innovation to become affordable and reliable. This issue was highlighted by the pilot scheme that LMLS had tested previously because the van had a low battery after only a few deliveries.

A problem that cannot be ignored is the "lack of energy infrastructure" to charge EVs. The LMLS has its own source of electric energy production, thanks to its internal infrastructure developed in previous years using institutional financing sources in a Public–Private Partnerships (PPP), so it is not relevant to this case. However, the replicability of this service is at risk with the current energy infrastructure especially if some regulations push for the conversion of public and private fleets in an entire region or country. In this case, the capacity of the facilities would not be enough, and energy sources would not be from Renewable Energy Sources (RES), hindering the positive externality created by EVs. For this reason, the interviews also mentioned an interest in future financing sources of sustainable electric mobility and logistics from Ministries and from the National Resilience and Recovery Plan (NRPP).

Taking a deeper look into "maintenance costs", in the opinion of the qualified interviewed subjects operating and maintenance costs will be an estimated four times lower in comparison with diesel ones: the examined experience of the LMLS is controversial compared to some studies mentioned in the literature (Digiesi et al. 2017) that highlight higher costs. This point suggests further research and analysis by looking at innovations in batteries and related technology.

"Working conditions" cannot be underestimated or neglected: drivers cannot run out of power because of air-conditioning. On the other hand, less polluting vehicles, both from a reduction in GHG and noise, could also improve working conditions for them, creating better operating conditions.

Another issue that needs to be considered is the "purchase cost" mainly because the price gap between LPG/diesel ones could make a difference for last-mile logistic services. In this case, already having an LPG fleet the environmental impact is lowered compared to a diesel one, so the price of changing the entire fleet could not be sustained easily until a curtailment of prices. At the same time, knowing the precise cost of these new electric vans and how much they would cut fuel and operating costs, could help to anticipate, or delay the decision to change the fleet.

Focusing on "technological development", it is crucial not only to have strong progress on battery capacity for hydraulic tails but deliveries to city centre shops could also need refrigeration, which requires a significant amount of energy. Underestimating this issue could replicate the previous pilot scheme or delay switching the LMLS fleet to electric.

Finally, high volatility in terms of prices on the electric market cannot be disregarded. This increases the level of uncertainty the company is going to face because of the cost of fuel for the vans. Particularly, even if in this case, the energy to supply the fleet is internally produced by LMLS, this uncertainty factor affects the whole supply chain.

5 Discussion

Deepening the analysis of investments, we addressed the topic from three different perspectives, Economic, Governance, and Social (ESG), to gather the most important effects on costs and benefits highlighted by LMLS managers: economic (Table 3), environmental (Table 4), and social (Table 5) aspects.

As mentioned previously, fuel prices could be an issue: in this historical moment, the price of electricity is more convenient than diesel. If energy sources are going to be more expensive and the ownership of infrastructure is not going to be enough to sustain EV charging, from an economic point of view it will be more efficient to utilise vans powered by diesel or LPG. Focusing on "delivery times" of the service, with electric vehicles, there is the possibility to create incentives for municipalities and regulators to limit access to UVARs and LEZs in city centres to decrease congestion:

Table 3 Economic perspective

Example of quotes	First-order codes
"Due to current fuel prices and future EU directives, electric energy at the moment is the most convenient, even if it is risky"	Energy consumption
"With UVARs that many situations are experiencing with sustainable vehicles, delivery times are facilitated"	Delivery times
"Costs of purchasing EVs are high, but in comparison with diesel powered vehicles maintenance costs are lower"	Purchase cost

Table 4 Environmental perspective

Example of quotes	First-order codes
"To decrease GHG emissions we started with methane vehicles, but in general, with EVs, we could also achieve noise reduction in urban centres"	GHG and noise emissions
"Traffic congestion with EVs is less polluting, but still a huge loss of time and safety issues"	Traffic congestion
"The challenge is also to the energy supply chain. If I use the energy produced from polluting sources, I nullify the environmental benefits"	RES energy supply

Table 5 Social perspective

Example of quotes	First-order codes
"Safety for workers is a priority, if more sustainable means of transport are also sustainable and noiseless, they could work in a better way"	Safety
"Sustainability could be improved by optimizing routes, in our case, the years of experience of drivers requires an optimization led by technology"	Worker expertise

this way there will be considerable time savings for couriers who can be more efficient in terms of time saved and so increase the number of deliveries. Decreasing the amount of congestion is going to have a positive impact on GHG and noise emissions, thanks to a decrease in both the number of vehicles in circulation and the lower environmental impact that EVs have (see Table 4).

Focusing on the positive and negative environmental externalities of this case study, using EVs has a major positive impact. Starting from GHG emissions and noise, substituting LPG with an electric fleet could make considerable improvements to reducing these kinds of negative externalities, starting from improving air quality, reducing sound emissions of the vans, and improving living conditions, not just for the population, but for the drivers too with better working conditions (see Table 5).

As mentioned above, the RES energy supply is a key factor to consider: if EVs are not charged with this kind of power the whole effort is going to eliminate the reduced negative externality.

Now routing optimization of LMLS is entrusted to human choice by highly skilled workers (>10 years of experience). However, they are not able to recognise the best route to decrease environmental impact, nor probably the most efficient way to improve timing or avoid congestion. Therefore, it is key for this kind of service to use a routing optimization algorithm, implemented with the digital twin application to be more efficient, not only from an economic and environmental point of view but also from operational and social perspectives. To have efficient routing optimization, it is crucial to re-design cities and industrial zones, create and/or implement UCCs and unloading parking and mid-delivery points, to reduce duplication of the same routes by drivers.

6 Conclusion

From the interviews analysed with the ESG criteria, the high cost of EVs is the main issue that discourages LMLS from switching their fleet from fuel to electric, similarly to other studies. Despite this factor, there is still a great deal of interest in these kinds of investments to anticipate the expected future needs for more environmentally sustainable logistics. From the various solutions to be faced the purchase cost and upgrade to necessary infrastructure, PPPs and institutional financing are two that emerged as the most important. Collaboration between municipalities and public institutions and possibly with trade associations must be encouraged to split the costs of these investments. This partnership would facilitate the creation of UVARs and LEZs and so congestion and the number of vans in circulation in city centres could decrease. Institutional financing is one of the most attractive and challenging paths to follow from the recent NRRP and other financing methods that Ministries could propose.

The major limit of this analysis is that it is based on interviews with a single operating subject, and does not include the companies that buy this service, the municipalities involved, and SMEs that are the destinations of deliveries. It could be of great interest to implement this study with interviews with these other subjects and inspect the possibility to implement UCCs, mid-delivery points near to city centres and especially, unloading parking, the possibility to activate new UVARs, possibly new LEZs, and moreover to understand the intention to adopt more restrictive policies towards electric transportation.

Finally, two aspects of the LMLS that were only indirectly mentioned in the interviews but are crucial to decrease the impact of this kind of service are neutrality and consolidation. Conglomeration of orders and consolidation of packages from different last-mile logistic companies to a neutral third-party company is one of the great challenges to improve efficiency of last-mile logistics. In this way, congestion and environmental impact could be reduced, creating several positive externalities.

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References

1. Boulaksil Y, Fransoo J, Blanco E, Koubida S (2014) Small traditional retailers in emerging markets, pp 460 460
2. Coulombel N, Dablanc L, Gardrat M, Koning M (2018) The environmental social cost of urban road freight: evidence from the Paris region. Transp Res Part D Transp Environ 63:514–532. https://doi.org/10.1016/j.trd.2018.06.002
3. De Magalhães DJAV (2010) Urban freight transport in a metropolitan context: The Belo Horizonte city case study. In: Procedia - Soc. Behav. Sci. Elsevier Ltd, pp 6076–6086. https://doi.org/10.1016/j.sbspro.2010.04.020
4. de Oliveira CM, De Mello Bandeira RA, Goes GV, Gonçalves DNS, De Almeida DM (2017) Sustainable vehicles-based alternatives in last mile distribution of urban freight transport: A Systematic literature review. Sustain. https://doi.org/10.3390/su9081324
5. Digiesi S, Mossa G, Rubino S (2012) Sustainable order quantity of repairable spare parts. IFAC Proc 45:181–186. https://doi.org/10.1109/SOLI.2017.8121002
6. Digiesi S, Fanti MP, Mummolo G, Silvestri B (2017) Externalities reduction strategies in last mile logistics: a review. Proc - 2017 IEEE Int Conf Serv Oper Logist Informatics, SOLI 2017 2017-Janua, pp 248–253. https://doi.org/10.3182/20121122-2-ES-4026.00043
7. Etikan I, Musa SA, Alkassim RS (2016) Comparison of convenience sampling and purposive sampling. Am J Theor Appl Stat 5(1):1–4. https://doi.org/10.11648/j.ajtas.20160501.11
8. European Commission (2021) Fit for 55. https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/
9. IEA (2021) Global CO2 emissions from transport by sub-sector in the Net Zero Scenario 2000–2030. https://www.iea.org/data-and-statistics/charts/global-co2-emissions-from-transport-by-sub-sector-in-the-net-zero-scenario-2000-2030. Accessed 7 Apr 2022
10. Janjevic M, Winkenbach M (2020) Characterizing urban last-mile distribution strategies in mature and emerging e-commerce markets. Transp Res Part A Policy Pract 133:164–196. https://doi.org/10.1016/j.tra.2020.01.003
11. Lebeau P, Macharis C, Van Mierlo J, Maes G (2013) Implementing electric vehicles in urban distribution: a discrete event simulation. In: 2013 World Electr. Veh. Symp. Exhib. IEEE, pp 1–10. https://doi.org/10.1109/EVS.2013.6914770
12. Paddeu D, Parkhurst G, Fancello G, Fadda P, Ricci M (2018) Multi-stakeholder collaboration in urban freight consolidation schemes: drivers and barriers to implementation. In Transport 33:913–929. https://doi.org/10.3846/transport.2018.6593
13. Patella SM, Grazieschi G, Gatta V, Marcucci E, Carrese S (2021) The adoption of green vehicles in last mile logistics: a systematic review. Sustain 13:1–29. https://doi.org/10.3390/su13010006
14. Schau V, Rossak W, Hempel H, Spathe S (2015) Smart City Logistik Erfurt (SCL): ICT-support for managing fully electric vehicles in the domain of inner-city freight traffic: a look at an ongoing federal project in the City of Erfurt, Germany. IEOM 2015 - 5th Int Conf Ind Eng Oper Manag Proceeding. https://doi.org/10.1109/IEOM.2015.7093862
15. The World Bank Group (2022) Urban Development. https://www.worldbank.org/en/topic/urbandevelopment/overview#1. Accessed 6 Oct 2022
16. Tipagornwong C, Figliozzi M (2014) Analysis of competitiveness of freight tricycle delivery services in Urban areas. Transp Res Rec J Transp Res Board 2410:76–84
17. Trott M, Baur NF, Landwehr MAD, Rieck J, von Viebahn C (2021) Evaluating the role of commercial parking bays for urban stakeholders on last-mile deliveries - a consideration of various sustainability aspects. J Clean Prod. https://doi.org/10.1016/j.jclepro.2021.127462

18. Wang Y, Zhang D, Liu Q, Shen F, Lee LH (2016) Towards enhancing the last-mile delivery: an effective crowd-tasking model with scalable solutions. Transp Res Part E Logist Transp Rev 93:279–293. https://doi.org/10.1016/j.tre.2016.06.002
19. Yin RK (2017) Case study research and applications: design and methods, 6th ed. SAGE Publications Ltd.
20. Zou X, Zhao F (2010) Research on growth mechanism of industrial cluster of logistics in coopetition. Proc Int Conf E-bus E-Government, ICEE 2010:2503–2506. https://doi.org/10.1109/ICEE.2010.632

Linking Urban Railways, People and Places: A Spatial Multicriteria Decision Analysis in the City of Catania

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Abstract The interconnection of urban contexts represents the baseline for the quality of life within them. An efficient urban mobility system ensures environmental, economic and social sustainability. It promotes inclusivity by fostering access to urban facilities and services. Moreover, it enables improvement to the organisation of urban space by allowing better allocation of city facilities. Urban railways connect the areas they cross by triggering relationships between these places, fostering the emergence of new centralities, urban regeneration practices and sustainable and inclusive mobility behaviour. This research proposes a model to study urban centrality through spatial data and multicriteria decision analysis. It shows a method to achieve a degree of centrality of station service areas according to different types of urban populations.

Keywords Centrality · Accessibility · Urban populations · Urban railway · GIS

1 Introduction

1.1 Urban Centrality, Mobility and Social Inclusion

Goal 11 of the 2030 UN Agenda focuses on "Sustainable cities and communities". In this framework, sustainable mobility is achieved by providing a safe, affordable, accessible and sustainable transportation system for all citizens [30]. Cities represent the human context in which opportunities are concentrated and where the mobility system has been strongly implemented. Hence, mobility becomes almost a synonym for the city itself [20]. Enhancing public transportation services is considered crucial, particularly in relation to the most vulnerable social groups [7, 19].

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Improving accessibility to places and services is an aspect of social equity [24]. An effective and inclusive mobility system influences the degree of sustainability of cities from environmental, social and economic points of view.

The concept of accessibility [1, 2] is presently included within citizenship rights because it can affect levels of social inclusion, equity and quality of life: it is "a matter of overcoming constraints of space at particular moments of time so as to gain access to the informal networks of work, leisure, friendship and family" [4: 548]. In other words, accessibility can be defined as the ease of supporting the material or temporal cost of reaching desired places. Constraints in urban movements can fuel inequalities that should be overcome through the implementation of suitable mobility policies. Recalling the concepts of the right to the city [17] and social production of the space [18], improving accessibility can create and strengthen spatial and territorial justice [13].

Facilities include various types of activities available in a city to satisfy people's needs, which are more accessible according to their availability in a space or if they are achievable through mobility practices. From a sociological perspective, the transportation system has to be considered in a study of accessibility [10]. The availability of public transportation services increases accessibility to urban resources, and they also help urban populations to achieve their goals and wishes. Centrality is a concept that summarises the degree of the appeal of a place in comparison to a surrounding periphery. According to Christaller [6], the model of central places depends on the quantity and levels of urban facilities offered. Central places benefit from higher-quality services and availability in larger numbers. The scattering of human settlements hosting activities and functions due to the evolution of transportation technologies and mostly private motorisation has affected the well-defined and highly gravitational spatial pattern [7].

Scientific literature identifies different types of urban populations [23, 27]. Each category has different needs and desires to be satisfied through the resources offered by a city. The intersection of urban populations and facilities shapes multiple scenarios of resource accessibility and the centrality of places. Mobility behaviour depends on the locations of different facilities, corresponding to the needs expressed by the inhabitants and all those who experience the city. Improving accessibility involves better distribution of facilities and improvements to public transportation services. A study of mobility necessarily requires the collection and analysis of spatially explicit data to investigate and understand the complexity of the phenomenon. Through an interdisciplinary and territorial approach, Geographic Information Science (GIS) supports a cognitive framework to provide a more successful use of urban space. Deeper and spatially explicit knowledge is necessary to support inclusive decision-making that is useful to foster sustainable mobility, reducing inequalities in access to facilities and services [31]. The construction of new transportation infrastructures, such as urban railways (i.e. metro lines or rail loops), represents an opportunity to improve the sustainability of cities, rethinking the organisation and centrality of urban areas. New relationships between the nodes of a transport network make it possible to change the conditions of centrality or peripherality that characterise the areas concerned, triggering potential changes in the social and economic fabric.

1.2 Study Area: The Geographical Framework of Urban Mobility

This study frames a representative case study of centrality and facilities by analysing the mobility dimension in the city of Catania, in Italy (Fig. 1). The city has a population of 301,104 people (ISTAT, as of 1 January 2022). It is home to an ancient university and has numerous services and activities. Moreover, it is a daily destination for commuters, students, tourists and more.

Since the 1970s, the city has been affected by a significant dispersion of residential settlements outside the historical city core, with the creation of neighbourhoods in the northwest and in the south [8]. Intense urban sprawl has led to congestion and pollution in the city centre [16].

Since 1986 [25], the city has been involved in the expansion of two urban railways: the subway and the rail loop. These projects could greatly contribute to solving the serious quality-of-life problems caused by excessive use of private vehicles. For example, in 2018, there were almost 72 vehicles per 100 inhabitants [15]. Since 2023, only one line and 10 subway stations have been working. By completing the infrastructural lines and their integrating service, the two urban railways could provide accessibility to important areas of the city through a single network. By exploring and investigating such urban development dimensions, this study provides the first insight into the contribution of railways to the potential of new urban centralities. Possible projects, if properly planned, could mix areas of the city that are not entirely coherent with one another and support urban regeneration processes. The relocation

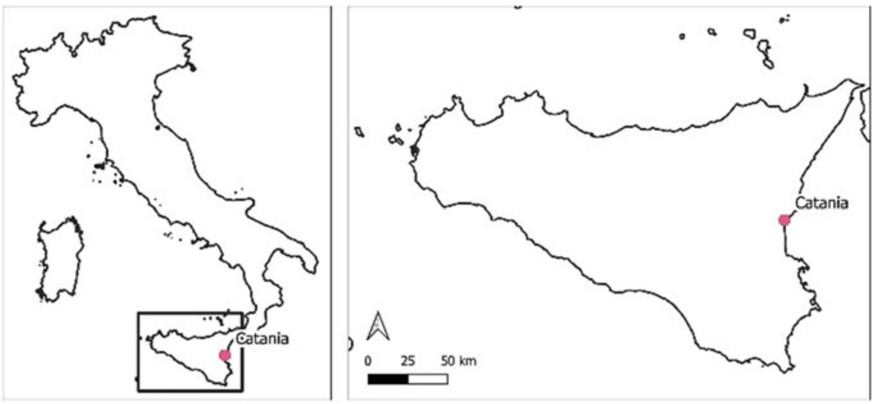

Fig. 1 Geographical location of the study area

of services to different neighbourhoods could lead to the creation of new centralities and improved quality of life.

1.3 Aims of the Study

The general aim of this study is to explore and reflect on the concept of urban centrality applied to the areas served by stations (service areas) regarding urban populations.

The specific aims are as follows: (i) testing a replicable way to measure the degree of centrality of each station's service area; (ii) identifying which type of urban railway user profile more frequently uses each station; and (iii) assessing future scenarios of urban centrality after the completion of a railway network in the city and its integration with a unified service.

2 Data and Methods

This study combined urban facilities and the profile types of populations by using spatially explicit data from OpenStreetMap (OSM) and other sources. Multicriteria Decision Analysis (MCDA) [21] was adopted to assess and quantify the degree of centrality of areas served by railway stations according to multiple urban facilities and user type profiles. MCDA encompasses numerous techniques for evaluating complex processes in which the heterogeneous elements involved affect them differently [12]. This approach is particularly useful to support decision-making in the public or private sector by involving stakeholders or citizens in participatory processes [11]. Data management and analyses were performed in a complete open-source GIS environment using QGIS software and different integrated plugins.

In the first phase of the spatial analyses, all the data were collected and geovisualised; then the two rail lines, the location of stations and the road network were extracted from OSM (as of 19 February 2021). The locations of railways and stations in progress or under construction were also obtained from municipality infrastructure plans [25, 26]. Spatial analyses were developed by performing two different territorial scenarios: (i) the present infrastructure dimension and (ii) the possible future layout, with infrastructure implementation and the integration of the two lines into a unified network.

The spatial units of analysis, or isochrony areas [28], were based on the locations of the stations (service area). Each of these corresponds to an area accessible through one of the railway stations, which is more or less equipped with facilities and is thus characterised by a different level of centrality. These areas represent the part of the city served by each station and its accessibility in terms of a set threshold of a 10-min walking time (5 km/h), considering the road network [3, 29].

Subsequently, 16 criteria were set to perform the MCDA analysis, corresponding to different selected urban facilities (Table 1).

Table 1 Selected criteria for Multicriteria Decision Analysis (MCDA), cartographic resources and supplementary information (OSM = OpenStreetMap)

MCDA criteria (facilities and services)	Source	Supplementary information
Grocery shops	OSM	*Shop: Bakery, butcher, convenience, deli, greengrocer, seafood, superm*
Bars/Kiosks	OSM	*Amenity: Bar + Shop: Beverages*
Cinemas	OSM	*Amenity: Cinema*
Libraries	OSM	*Amenity: Library*
Pharmacies	OSM	*Amenity: Pharmacy*
Places of worship	OSM	*Amenity: Place_of_worship*
Schools	OSM	*Amenity: School*
Services	OSM	*Amenity: Arts_centre, Bank, Clinic, Hospital, Police, Post_office*
Sport facilities	OSM	*Sport: (all the values)*
Shops	OSM	*All values except those considered in other categories*
Theatres	OSM	*Amenity: Theatre*
Tourism sites	OSM	*Tourism: All values*
Universities	OSM	*Amenity: University*
Urban intermodality	Metropolitan Transportation Company (AMT)	Bus line shapefile data are extracted; then the number of lines passing through each iso-area is calculated
Suburban intermodality	OSM	Railway stations, suburban terminals and the airport are considered (whose placement was forced from original in OSM data)
Public green spaces	Territorial Information System (Catania Municipality)	Categories of public green spaces considered: children's playgrounds, historic gardens, equipped green space

The majority of the spatially explicit data were derived from OSM, which allows for the extraction of information based on a pair of key value attributes corresponding to the data of interest. The data were obtained directly in QGIS through the QuickOSM plugin; hence, data corresponding to many different services, amenities, stores and facilities were extracted. Public green space data were obtained from the Territorial Information System of Catania Municipality (as of 15 March 2021), whereas bus lines were extracted from open-access General Transit Feed Specification (GTFS) data by the Catania Metropolitan Transportation Company (as of 17

March 2021). Hence, a count of each type of facility in each area was performed for point data from OSM and bus routes. For public green space areas, the percentage of occupied areas compared to the station service area was calculated. Moreover, the collected data were merged into a single attribute table of the layer containing polygons corresponding to the service areas.

The VectorMCDA plugin [22] was used for MCDA analysis, performed using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methodology, that "rates the decision alternatives under consideration according to their multidimensional distance to the ideal point using the distance metric" [21: 102]. Weights are set to evaluate decision alternatives that can have a positive or negative contribution. The best alternative is placed at the shortest Euclidean distance from the ideal situation and at the greatest distance from the worst one. In this study, urban facilities are the decision alternatives, considered with a positive contribution. The decision table, with the decision criteria (Table 2), was established by rating each urban facility from 1 to 10 (from the least to the most important), according to each user profile considered (student, city user, commuter, inhabitant, tourist, city leisure user). The table was elaborated by the Members of the research group "Climate Change, Territories, Diversity" of ICEA Department, University of Padua (Italy) by prioritising and weighting the selected criteria. The weight assigned was identified by dividing each rating by its sum, with the values derived having a sum equal to 1. Weights were assigned according to the importance of the relative profile.

In VectorMCDA's GeoTOPSIS procedure, all weights were added considering gain. Consequently, each element increased the level of centrality obtained. In MCDA, the data included in the table were all normalised. The assigned weights, structured in a spreadsheet, were then reported in the plugin interface. Based on these weighted criteria and the distance calculation, normalised values in a range from 0 to 1 were derived as the degree of urban centrality. This procedure was recursive for each identified user profile. A differentiated station centrality value was therefore obtained according to each urban population profile.

3 Results and Discussion

Using a kernel density map, initial spatial analysis highlights all urban facilities (Fig. 2). The cartographic representation makes the intensity of resources near some already operating stations visible (e.g., Stesicoro, Italia, Giuffrida and Borgo). Other densely populated and suburban neighbourhoods near the Verrazzano and Librino stations, which will be reached in the future by the subway, are poorly equipped.

Moreover, it is possible to discriminate differences in the representation of centrality by the identified values based on MCDA analysis. For each profile chosen, the centrality values are represented in a single map. According to the highest centrality values achieved in different service areas, one or more characterising labels can be assigned to the corresponding stations depending on the prevailing type of potential users. Giovanni XXIII, Giuffrida and Borgo are commuter stations at which

Table 2 Ratings and weights for each user profile and urban facilities

	University students		City user		Commuters		Inhabitants		Tourists		City leisure user	
Grocery shops	7	0.07	5	0.06	5	0.08	10	0.09	5	0.06	5	0.05
Bar/kiosks	8	0.08	8	0.10	8	0.12	8	0.07	8	0.10	8	0.09
Cinemas	5	0.05	3	0.04	3	0.05	8	0.07	2	0.02	9	0.10
Libraries	6	0.06	5	0.06	3	0.05	6	0.05	2	0.02	4	0.04
Pharmacies	6	0.06	5	0.06	3	0.05	7	0.06	5	0.06	5	0.05
Places of worship	4	0.04	4	0.05	3	0.05	7	0.06	4	0.05	4	0.04
Schools	1	0.01	1	0.01	1	0.02	5	0.04	1	0.01	1	0.01
Shops	5	0.05	7	0.09	3	0.05	7	0.06	5	0.06	8	0.09
Sport facilities	5	0.05	4	0.05	3	0.05	8	0.07	2	0.02	5	0.05
Theatres	5	0.05	3	0.04	3	0.05	8	0.07	5	0.06	9	0.10
Tourism	4	0.04	5	0.06	2	0.03	4	0.03	10	0.12	7	0.07
Universities	10	0.10	1	0.01	1	0.02	5	0.04	2	0.02	1	0.01
Urban intermodality	10	0.10	10	0.12	10	0.15	8	0.07	10	0.12	7	0.07
Public green areas	8	0.08	8	0.10	5	0.08	9	0.08	8	0.10	8	0.09
Suburban intermodality	7	0.07	7	0.09	8	0.12	8	0.07	9	0.11	7	0.07
Services	5	0.05	5	0.06	5	0.08	8	0.07	6	0.07	6	0.06
SUM	**96**	**1**	**81**	**1**	**66**	**1**	**116**	**1**	**84**	**1**	**94**	**1**

modal interchange occurs, while university student stations are those that provide access to the most important sites of Catania University or where commuter students perform modal interchange with other systems (i.e., Stesicoro, Giovanni XXIII, Italia, Borgo and Nesima). Notably, due to its proximity to the university campus, the Milo station is particularly frequented by student users. The most central stations for urban dwellers are Italia, Giuffrida and Milo due to the presence of services and commercial activities. The Stesicoro station, thanks to the mix of facilities that it provides, has high values on all profiles, with a particular emphasis on tourists and city leisure users. Some results are presented in Fig. 3a and b.

By adopting a recursive approach to this procedure to obtain the completed infrastructure scenario, it is possible to geovisualise and investigate it on the basis of the current data on urban facilities. The evidence is of low centrality configuration related to some stations that will be built in neighbourhoods currently considered peripheral (e.g., Librino, Verrazzano and San Leone). In fact, there are few available urban facilities in those areas, as shown in Fig. 4, despite being characterised by a high-density

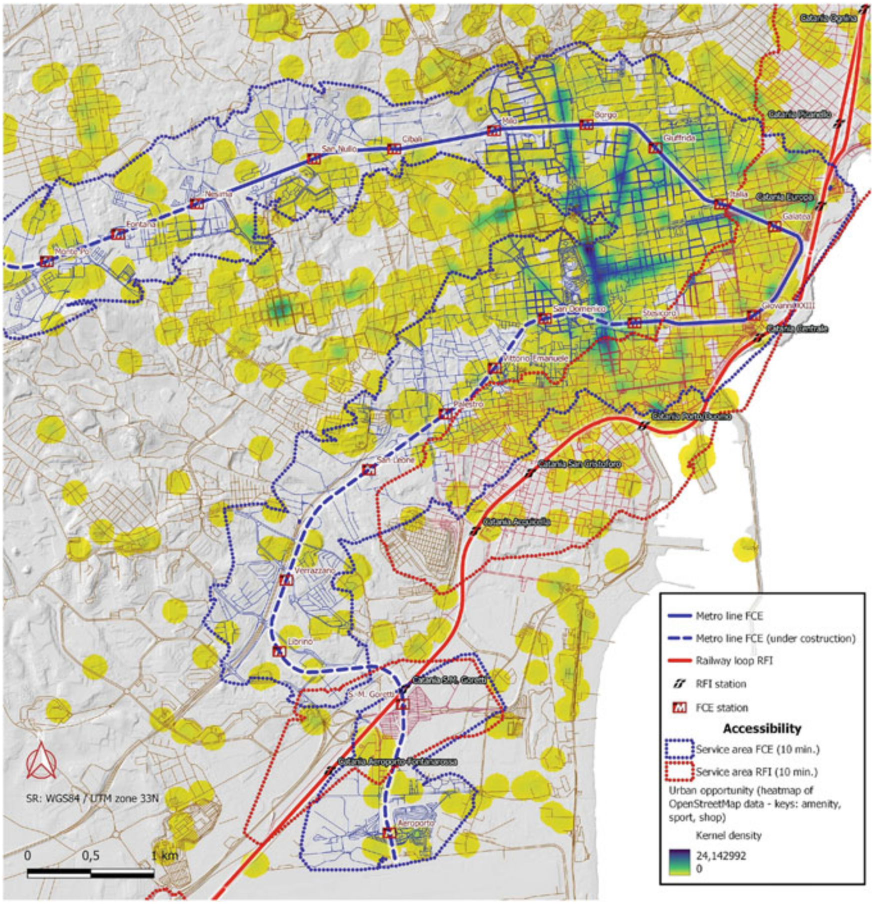

Fig. 2 Kernel density map of urban facilities

population. In this case, the results might have been affected by the few attractive resources and reduced mapped features in the OSM collaborative platform.

The creation of stations might be an essential reason for the placement of new services and the emergence of new activities. During infrastructure implementation over time, changes in opportunity supply may affect the criteria and weights considered to perform simulated scenarios by MCDA analysis.

In general, MCDA analysis highlighted how in future scenarios, new stations and the extension of the railway could provide more centrality to areas that are presently peripheral by creating an opportunity to (i) reconnect the involved urban areas, (ii) change centre/periphery relationships through better urban planning, (iii) relocate services and (iv) create new appeal.

Notably, the entire process is based on and related to data on existing resources. Moreover, the extreme best and worst values employed in the MCDA, related to

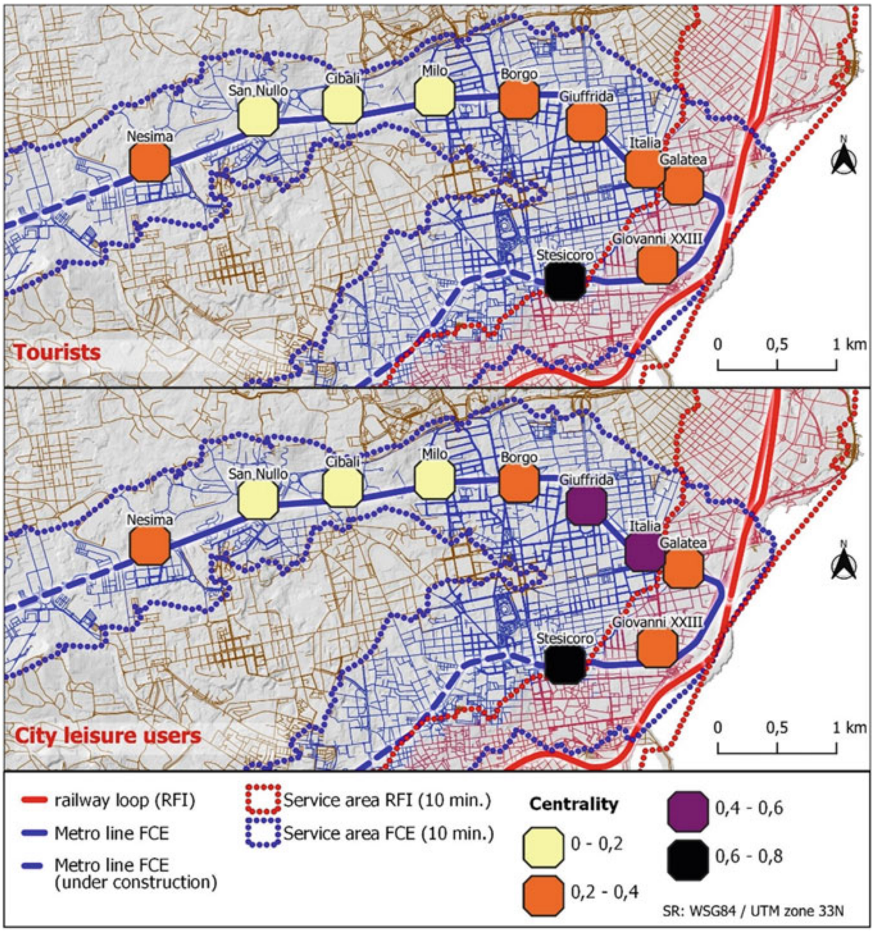

Fig. 3 **a** Urban centrality varies based on two types of urban population: tourists and city leisure users. **b** Urban centrality varies based on three types of urban population: university students, city users, commuters

each decision alternative, correspond to the maximum and minimum levels of urban facilities based on the data collected; therefore, they are related to this case study. They do not represent a valid scale in an absolute sense and thus are not able to confirm the sufficient availability of each resource type. Moreover, in MCDA, the weights could be chosen in a different way by the direct involvement of policymakers and citizens in weighing operations. Further development of this study may also consider elements that can negatively affect centrality, such as degraded places, crime, abandoned urban areas, traffic and pollution. In fact, elements that affect the phenomenon negatively or positively (cost and gain) can be included in the TOPSIS

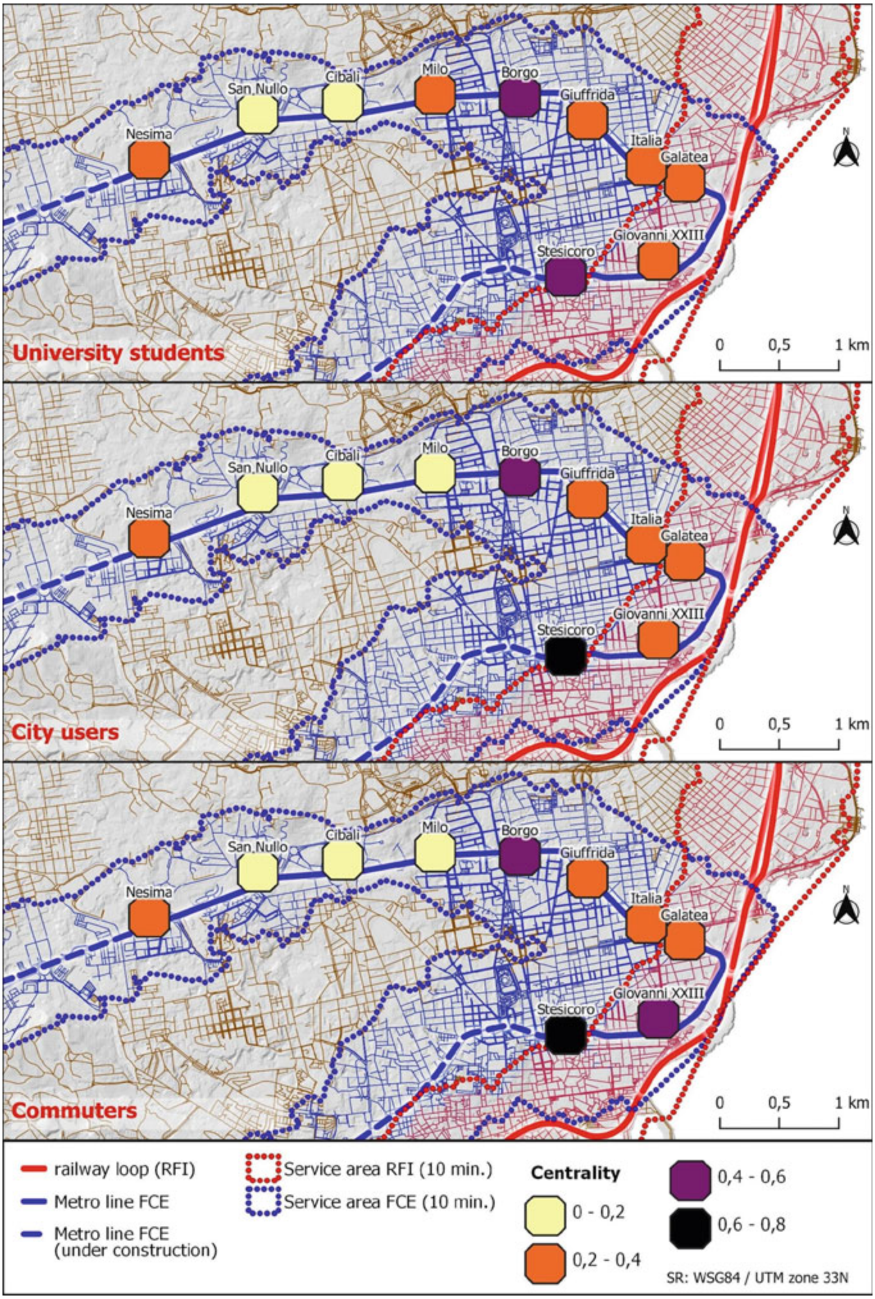

Fig. 3 (continued)

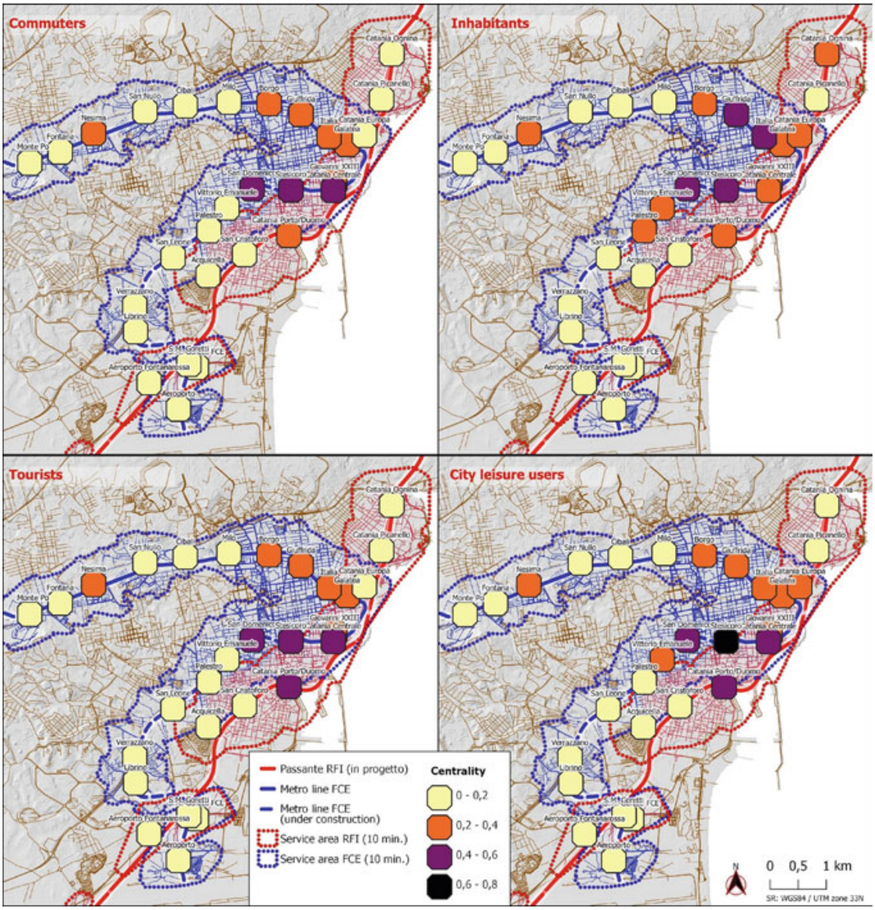

Fig. 4 Urban centrality varies in a completed infrastructure scenario, based on four types of urban population: commuters, inhabitants, tourists and city leisure users

procedure. In this study, all features contributed to the degree of centrality, and consequently, were all considered positives (gains).

4 Conclusion

This study shows how an apparently objective and unique concept such as centrality should first be defined, starting from the spatial dimension of different urban populations and the most vulnerable social groups. Therefore, it is necessary to adopt a perspective that considers centrality on the basis of different needs and desires related to the spatial distribution of residents and territorial features and services.

The proposed model provides the possibility to achieve this goal, as it is replicable and scalable to other urban contexts by analysing user profiles as long as data is available. The analysis of phenomena using spatially explicit data and GIS-based tools constitutes an additional important cognitive contribution that cannot be excluded from the urban planning decision-making process.

More detailed availability of data on urban facilities or comparison with actual data on working station users would achieve further cognitive ends and refine the proposed model. For this reason, it is important to highlight the importance of collaborative mapping activities on open-access platforms, such as OSM, and to share open data on mobility with transportation companies and territorial administrations.

Comparing actual situations with future scenarios highlights the risk that areas of centrality will remain restricted to those of today. This projection suggests the importance of secondary actions in the construction of metropolitan railways. There is a need to encourage the reuse of abandoned spaces, the redevelopment of new neighbourhoods with the implementation of services and activities and the restoration of historic suburban neighbourhoods with regeneration measures.

Some of these changes may be generated spontaneously and are consequential to infrastructure development. Coordinated intervention is also necessary to avoid the production of further imbalances and the creation of dynamics that are far removed from sustainability models and the real needs of urban populations.

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References

1. Borlini B, Melzi C, Memo F (2011) Mobilità, accessibilità ed equità sociale. Sociologia Urbana e Rurale 94:86–102
2. Borlini B, Memo F (2009) Ripensare l'accessibilità urbana. Cittalia Fondazione ANCI ricerche, Rome
3. Bonotti R, Rossetti S, Tiboni M, Tira M (2015) Analysing space-time accessibility towards the implementation of the light rail system: the case study of Brescia. Plan Pract Res 30(4):424–442
4. Cass N, Shove E, Urry J (2005) Social exclusion, mobility and access. Sociol Rev 53:539–555
5. Catania Metropolitan Transportation Company, General Transit Feed Specification (GTFS), 17 March 2021
6. Christaller W (1933) Central places in southern Germany. Prentice Hall, Englewood Cliffs, NJ
7. Colleoni M (2019) Mobilità e trasformazioni urbane. La morfologia della metropoli contemporanea. Franco Angeli, Milan
8. Catania Municipality (ed) (2012) Piano Generale del Traffico Urbano
9. Catania Municipality, Territorial Information System. https://sit.comune.catania.it/geonext-ctw/guest.html. Accessed 15 Mar 2021
10. Daconto L, Colleoni M, Gwiazdzinski L (2017) L'accessibilità spaziale potenziale alle opportunità urbane. Un'analisi comparata tra la città metropolitana di Milano e la metropoli di Lione. Archivio di Studi Urbani e Regionali XLVIII 119:73–91

11. Geneletti D (2019) Multicriteria analysis for environmental decision-making. Anthem Press, London, New York
12. Greene R, Devillers R, Luther JE, Eddy BG (2011) GIS-based multiple-criteria decision analysis. Geography Compass 5(6):412–432. https://doi.org/10.1111/j.1749-8198.2011.00431.x
13. Harvey D (1973) Social justice and the city. Edward Arnold, London
14. ISTAT (2023) Municipal resident population by sex, year of birth and marital status. http://dati.istat.it. Accessed 4 Mar 2023
15. ISTAT (2018) Vehicles—Public vehicle register—municipalities. http://dati.istat.it. Accessed 4 Mar 2023
16. La Greca P, Martinico F, Barbarossa L (2013). Progettare la città transit oriented: mobilità sostenibile e pianificazione urbana per la città di Catania, Conference Paper. In: XVI Conferenza Nazionale SIU - Società Italiana degli Urbanisti, Napoli
17. Lefebvre H (1968) Le droit à la ville. Anthropos, Paris
18. Lefebvre H (1974) La production de l'espace. Anthropos, Paris
19. Lucas K (2012) Transport and social exclusion: Where are we now? Transp Policy 20:105–113. https://doi.org/10.1016/j.tranpol.2012.01.013
20. Kaufmann V (2011) Rethinking the city—Urban dynamics and motility. Routledge, Oxford
21. Malczewski J, Rinner C (2015) Multicriteria decision analysis in geographic information science. Springer, New York
22. Maplab (2015) Manual VectorMCDA. http://maplab.alwaysdata.net/doc/html_VectoMCDA/manual.html. Accessed 4 Mar 2023
23. Martinotti G (1993) Metropoli. La nuova morfologia sociale della città. Il Mulino, Bologna
24. Mattioli G, Colleoni M (2016) Transport disadvantage, car dependence and Urban form. In: Pucci P, Colleoni M (eds) Understanding mobilities for designing contemporary cities. Springer, pp 171–190. https://doi.org/10.1007/978-3-319-22578-4
25. Mobilita Catania (2022) Metropolitana di Catania: storia e sviluppi futuri. https://catania.mobilita.org/opere/metropolitana-di-catania-storia-e-sviluppi-futuri. Accessed 2 Mar 2023
26. Mobilita Catania (2018) Passante Ferroviario di Catania. https://catania.mobilita.org/opere/passante-ferroviario-nodo-di-catania. Accessed 2 Mar 2023
27. Nuvolati G (2007) Mobilità quotidiana e complessità urbana. Firenze University Press, Florence
28. O'Sullivan D, Morrison A, Shearer J (2000) Using desktop GIS for the investigation of accessibility by public transport: an isochrone approach. Int J Geogr Inf Sci 14(1):85–104. https://doi.org/10.1080/136588100240976
29. Rossetti S, Tiboni M, Vetturi D, Zazzi M, Caselli B (2020) Measuring pedestrian accessibility to public transport in Urban areas: a GIS-based discretisation approach. Eur Transp (76), Paper no 2
30. United Nations (2021) Sustainable transport, sustainable development. Interagency report for second Global Sustainable Transport Conference
31. Van Maarseveen M, Martinez J, Flacke J (2019) GIS in sustainable urban planning and management. A global perspective. CRC Press, Boca Raton, FL

Commoning Practices Along Streetscapes

Elisa Ravazzoli

Abstract In many cities around the world, similar stakeholders are collectively implementing initiatives that aim to address common problems, satisfy similar unmet needs, and contribute to the creation of more socially just and ecologically sustainable communities. Among the different types of action, commoning practices propose alternative forms of caring, sharing, protesting, producing, consuming, and occupying, where resources are collectively produced, owned, managed, or distributed. This paper seeks to theoretically reflect on the transformative power of commoning occurring on streets to tackle contemporary challenges and aims to suggest a framework for the socio-spatial analysis of commoning practices on streets.

Keywords Urban commons · Commoning practices · Governance · Sustainable cities and communities

1 Introduction

Societies across the world are facing severe social, environmental, and technological challenges that are significantly impacting the built environment and citizen's daily lives. To foster the transition towards more sustainable, beautiful, and inclusive cities and communities, the EU has launched several initiatives among which the EU Pillar for Social Rights, the New European Bauhaus, the Green Deal, the Digital Compact, and many more. Among these, the New European Bauhaus asks all Europeans to imagine and build a sustainable and inclusive future together that is beautiful for our eyes, minds, and souls. More than ever before policymakers, civil society organizations and citizens are being asked to work together to re-think and re-shape our cities, communities, and public spaces as well as the way we live, move, work, and consume to promote a transformation towards more resilient, economically sustainable, and socially inclusive places and cities. Together with institutionalized players, many non-formal stakeholders have already started to develop bottom-up initiatives

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aiming to find concrete solutions to pressing problems facing human society (e.g., climate change; social exclusion; socio-spatial inequality), or to respond to unmet citizens' needs that the market or the state is not able to fully satisfy (e.g., provision of services; reclaiming the right to the city). Among existing collaborative and bottom-up initiatives taking place in our cities, we could mention the following: activist movements where people reclaim streets as places of shared interest, collective decisions and collective work (Stavrides 2016); collaborative pacts where citizens and public administrations sit at the same table to negotiate the shared use of unused or confiscated mafia spaces to meet needs and turn them into common goods (Collaboration Pacts Archives—Labsus); urban commons, where resources are collectively produced, owned, managed or distributed by a community for their mutual benefit in a sustainable manner (Harvey 2012).

This work is part of the research field into urban commons and focuses precisely on commoning practices happening in public spaces, mainly along streets. A commoning practice is a process according to which a community collectively creates, reproduces, and co-manages resources. Streets have often been considered as commons in the past to host many forms of social practices (Harvey 2012). In the course of history due to car-oriented planning, streets have lost their human and social dimensions; due to the consumer society streets have also been gradually privatized losing their public character (Mitchell 1995). Nevertheless, people are still seeing streets as places of *shared interest*, *collective decisions,* and *collective work* (Stavrides 2016). Many commoning practices occur along city streets (urban gardening, protests, climate movements); and people gather in streets to find shared ways to satisfy similar unmet needs through collective action; they use streets to protest and for social activities.

The literature on urban commoning is extensive; however, there is still a gap in the investigation of the relationships between "streets" and "commoning", a topic not widely addressed so far. Even though there is literature on how streets may be considered as commons, few studies have analysed bottom-up initiatives as commoning practices occurring in streets. An example is provided by the work conducted by Rosol (2018) who studied urban gardening as an urban commoning practice in the context of neoliberal urbanism.

Indeed, many bottom-up initiatives may be reconsidered as commoning practices, primarily due to their potential to produce new forms of common space (Stavrides 2015: 11). So conceived, commoning practices occurring in streets have a transformative power on both spatial and social dimensions: on the one hand, they can increase the aesthetic and physical quality of streets; restore existing local resources that are important for the local population to satisfy their needs and livelihoods (existing parks; vacant lots); on the other hand, they can empower citizens, no-profit associations, local figures and people in general to protect, care for and take responsibility for the use of existing resources in a collective way, following principles of solidarity, sharing and caring.

Given this framework, this paper has a threefold objective: (1) map commoning practices occurring in streets to discover the different types of challenges addressed; (2) propose an analytical framework to investigate the social and spatial dimensions of street commoning; (3) contribute to a better understanding of the transformative power of commoning practices. The underlying hypothesis is that commoning practices can contribute to making streets more sustainable, beautiful, and inclusive (New European Bauhaus values) and can contribute to making communities socially just *and* ecologically sustainable (Agyeman et al. 2003), i.e., communities able to provide equitable access to green space, clean air and water, healthy food, affordable good-quality housing, and safe neighbourhoods. This paper is structured as follows: Sect. 2 presents a review of the literature on commoning practices along streets; Sect. 3 is about presenting a framework of analysis; Sect. 4 presents an example of commoning practices; the final section presents some discussion, conclusions, and open questions.

2 Literature Review on the Social and Spatial Dimensions of Commoning Practices

The term "commoning" was originally coined by Peter Linebaugh (2008) in his attempt to highlight aspects of the commons that are linked with activities and not with material resources. In literature, there are many definitions of commoning. The concept has been widely investigated in the field of urban planning (Stavrides 2014, 2016; Bingham-Hall 2016; Sohn 2019). Growing scholar attention on commoning practices rather than commons (Euler 2018) is related to both the academic and practical needs of unfolding the collective processes of alternative forms of ownership, production, and governance (Bresnihan and Byrne 2015) that happen daily in urban spaces to meet collective needs and desires. Commoning suggests a new vocabulary to explain "the social practices that enable people to discover, innovate and negotiate new ways of doing things for themselves" (Bollier and Helfrich 2012). Commoning has also been explained as a way of "creating a common culture" in partnership with other stakeholders (Pór 2012). Commoning highlights the notion that commons can only be managed through social relationships and shared knowledge (Bollier 2014). Overall, commoning refers to a network of relationships and social practices that are based on a shared understanding that some things belong to all of us, and that collective decisions and actions can shape the future without being locked into profit-driven mechanics.

Among the most used conceptualizations of commoning, particularly relevant to the scope of our work are those of: David Harvey, Stavros Stavrides, Massimo De Angelis, Chatterton and Bollier & Helfrich. They link social practices, the community of commoners and the social, political, and spatial environment in which they occur.

Harvey (2012: 73) defines commons not as resources or assets but as social relations and suggests understanding it as a verb—*commoning*—as a social practice. According to Harvey's definition, we can talk about social practices of commoning when there is an unstable social, collective, and non-commodified relation between a self-defined social group and *those aspects of its actually existing or yet-to-be-created social and/or physical environment deemed crucial to its life and livelihood* (Harvey 2012: 73).

Stavrides refers to commoning as an *inventive process* that produces new forms of social life, shared experiences and knowledge that can challenge capitalism (Stavrides 2016: 99, 107): new ways of *appropriating and using the city* (ibidem 99) are developed *through collective decisions* and actions (ibidem 107), according to the collective needs and aspirations of a community of common space users. Commoning practices also have a strong spatial dimension. There are a set of spatial practices through which space is created. Space is not only a product and therefore a stake for commoning but a means of establishing and expanding commoning practices (Stavrides 2016).

In the De Angelis' commons system, commoning, or doing in common, is a specific multi-faceted social activity, *characterised by modes of production, distribution and governance of the commons that are participatory and non-hierarchical* (De Angelis 2017: 121), whose effects on the commons environment may be that of spreading culture or values. Euler (2018) defines commoning as a process that creates, reproduces, and co-manages the community goods of a community; in explaining the "community" that manages communal goods, De Angelis (2017) indicates that it is a collection of people who share resources according to rules they themselves set out and are united around a common agenda, which they share and pursue together. As stated in Centemeri's work (2018), based on the De Angelis' definition of commoning, these alternative practices must be directed towards global goals of *emancipation, social justice, and ecological sustainability* (293), to be truly subversive.

According to Bollier and Helfrich (2019), commoning practices are embryonic forms of alternative modes of production and livelihood characterized by social interaction and a bottom-up mode of participative decision-making (Bollier and Helfrich 2019). They are an exploratory process through which people identify their needs and develop specific systems for provisioning and management. They are characterized by three elements referring to the social, economic, and institutional spheres: (a) social practices and the relationship between human and non-human (social life); (b) the act and modality of producing together (provisioning), (c) governance across the members (Peer governance).

Finally, Chatterton (2010) defines urban commoning as *processes of collective (not necessarily open access), cooperative, non-commodified creation, maintenance, protection, and transformation of urban spaces.*

These excursus of definitions and stream of thinking helped to identify the key elements of commoning practices that will be used to propose a framework of analysis (Sect. 3).

3 Framework of Analysis

The analytical framework integrates dimensions coming from different theoretical backgrounds. The social dimension of analysis is built by merging the concept of social innovation as theorized by Secco et al. (2019) with the concept of commoning practices as theorized by Bollier and Helfrich (2019: 98) and the concept of commons as theorized in the work of Ostrom (1990). The spatial dimension of analysis refers mainly to the work of Oliveira (2016). These dimensions of analysis (Tables 1 and 2) allow us to examine: how and where practices are produced by whom, for which purpose, how resources are managed and how practices modify the physical space in which they occur. The table incorporates dimensions of analysis that are relevant to the authors based on a literature review, but it does not intend to be exhaustive. Moreover, the framework proposed has only been partially tested. Information on the selected practices was collected only for the analytical dimensions that were already tested in other projects/case studies (e.g., description, agency, context, needs, physical elements of the streets, land use). Full application of the framework is part of a future project in which the authors will select five different case study practices and study them in detail.

Information on the social dimension can be retrieved by using a mixed method approach (e.g., open interviews; semi-structured interviews; field observations; surveys) and via desk research (secondary data collection). The information helps to contextualize the practices and to understand the socio-economic and cultural structural dimensions that generate them; as well as to investigate how practices are socially produced, by whom and for what reasons; finally, the information enables us to investigate also how practices are managed, how the relationship between commoners occurs, the types of organization structure, and how space is collectively experienced and perceived by the people.

Information on the spatial dimension can be collected via maps, architectural diagrams, pictures, and texts generated directly by the people involved in the practices and retrieved via interviews or published online. The information is useful to perform a spatial analysis, which consists in investigating the space before, during and after the practices, and in understanding how the space has been spatially produced, modified, and experienced by the people involved in the practices; considerations will be made on the implications on the level of city forms/urban planning/urban design. This exploration is interesting as it allows us to focus on the possible links between how the city has been planned to use spatial elements and how these physical and social elements are used and can foster sustainability.

Table 1 Social dimensions of analysis and descriptions

Dimension	Description
Starting date	Year in which the practice appears for the first time
Starting location	City/neighbourhoods/streets where the practice took place for the first time
Geographical scale	Spatial dimension where the phenomenon is taking place that can be local, regional, national, global
Type of practice	Concrete activity and actions
Institutional form	Legal status of the practice (legal, illegal) and funding arrangements
Context, agency collective needs (Secco et al. 2019)	*Context*: Conditions that enable or constrain the practices to occur and may refer to both local and global conditions
	Agency/Community: Stakeholder capacity to mobilize and transform existing resources. It consists of (a) their characteristics, ideas, values and capacity for change and types of stakeholders and knowledge; (b) concrete actions and preparation actions to implement communing practices; (c) relationships
	Collective needs: refers to the needs/challenges to which a practice should respond and address as part of its effects. It includes some sub-dimensions: Trigger; unmet needs; societal challenges. *Trigger*: refers to a punctual event or situation that causes something to start. It is an event that determines or accentuates needs—to the point of deserving a response and a change in practice. *Unmet needs* refer to demands posted by society that are not satisfied by the state/market and for which a solution needs to be found. *Societal challenges* refer to something that needs great mental or physical effort to be done successfully. They refer to social, economic, institutional, and environmental challenges that require the adoption of adaptation strategies
Scale up/out (Secco et al. 2019)	Processes of upscaling. Scaling out consists of replicating, adapting or aggregating practices; Scaling up consists of including the practices in changes in policy at a higher level and in having effects on a higher scale. Scaling up is not always possible, as the practices may depend on locally specific social relationships and contexts which are not present at different spatial and socio-economic levels
Social life, provisioning, peer governance (Bollier and Helfrich 2019)	*Social life:* refers to specific forms of cooperation, sharing, and ways in which people relate to each other by sharing values and building a culture of commonality and shared identity
	Provisioning: the "act of production in common" or "provisioning through pooling" by people who satisfy their needs by producing things or services together. Through common goods, people can merge their social and economic needs, providing the basis for production and consumption

(continued)

Table 1 (continued)

Dimension	Description
	Peer governance: the continuous process of dialogue, coordination, and self-organization between people who are active participants in the collective process of creation
Eight design principles of commons systems by (Ostrom 1990)	Clearly defined boundaries Congruence between rules and local conditions Collective choice arrangements Monitoring: effective controls Graduated sanctions Conflict resolution mechanisms Recognition of rights to organize Nested enterprises

Table 2 Spatial dimensions of analysis and description

Dimension	Description
Physical elements of the streets (Oliveira 2016)	Dimensions of the street (width, soil permeability and materials) Design elements (lighting systems, waste collection, road equipment, bike racks) Space for vehicles (roadways, parking lots, bus lanes, bike lanes) space for pedestrians (sidewalks, benches) Architectural elements of facades on streets (height, style, empty walls, shop windows)
Land use distribution (Oliveira 2016)	Space dedicated to green spaces (flowerbeds, trees) Main functional uses (i.e., shopping streets, residential streets) spaces dedicated to social and commercial activities already in place (daily/monthly) Traffic levels during the day and at night
	Temporary practices performed by, i.e., street vendors, illegal practices

4 Emerging Commoning Practices

To map out different types of commoning practices taking place along streets and their specific socio-spatial features (e.g., type of people, spatial contexts, types of changes enhanced, modifications of implied power, inclusiveness), we created a database of examples by means of desk research. The database was developed in Excel and compiled using a range of sources including academic literature, project reports and input from expert colleagues. The database is a useful tool to distinguish socio-spatial differences across practices as it lists the key dimensions in the columns (e.g., scale, topic and sector, agency, for scaling see the paragraph before for the full list) while the information describing the commoning practices is placed in rows. As of 31 July 2019, the day the data collection ended, 20 examples had been inserted into the database. Of these, 4 related to *Green Care*, 3 related to *Political Activism*, 5 related to *Community Care*, 3 related to *Recreation*, and 5 to *Social Justice*. The database is not exhaustive but only illustrative. The societal challenges these practices want to address refer mainly to environmental justice, social inclusion, and socio-spatial justice. The practices developed more easily in the USA and Europe with New York and Italy the main focus; since the research was done in Italian and English this could also explain the results. The examples refer to practices dealing with activities that happen in city public spaces: Play, occupy, acting/expressing, community care, selling staying, walking, etc. The examples selected highlight the effectiveness of spontaneous and informal actions in terms of: (a) collective control of the territory, protection and security; (b) community services (activities that respond to collective needs); (c) promotion of tolerance (c.f. rethinking the culture of tolerance) and multicultural engagement; (d) conflict management, fighting social exclusion; (e) social capital, knowledge and interpersonal skills. Most of all the practices have both a local and global dimension and have a trans-local character, which, in a globalized world, is a common and desired trait to have processes that produce close interrelations between places and people that are far away and different. However, like many social innovation initiatives, commoning practices have a global character but act at local level with the capacity to generate strong impacts mainly at a local community level. Below is an example describing guerrilla gardening, an initiative that was developed on the streets of New York, which then spread across the world, taking slightly different forms through time and space (Fig. 1).

5 Discussion and Conclusion

This paper discusses the relationship between streets and commoning practices; it proposes an approach to analyse how commoning practices are produced socially as well as how they modify the physicality of space, leaving concrete signs in the urban context; also, it maps some existing commoning practices on streets. This section discusses some considerations on the transformative power of commoning practices on streets, i.e., how commoning practices manage the resources available and change social relations among individuals.

Commoning practices, consisting in action taken by individuals, groups and networks of people, with various motivations, should be seen in different ways: (a) as an opportunity to innovate the provision of urban services; (b) as a possibility to develop alternative economies, sometimes both out of the market exchange and state provision and towards a collaborative economy that drives local development and to promote transformation towards a more socially just and ecologically sustainable societies; (c) as a way to reclaim the “right to the city” and use existing available spaces; (d) and finally as a way to promote an inclusive regeneration of spaces using place-making, i.e., the intentional effort to create good public spaces to promote

Fig. 1 Display of an example of Guerrilla gardening commoning practice (key dimensions). Credit @ https://www.guerrillagardening.it/pagina2.html

people's well-being. Overall, streets can be transformed via commoning practices into resources for community development and empowerment as well as tools for designing better public spaces.

By dismantling the idea of "public" or "private property" towards shared ownership and stewardship, commoning practices suggest alternative ways of living, producing, and consuming that are based on values of caring for or/and sharing with. In many cases (e.g., food production, social economy), commoning practices provide a service where citizens and communities have an active responsibility; thus, citizens are moving away from being purely consumers to becoming consumers *and* producers of our cities and society (Sofia 2017). In so doing, commoning practices are fostering an equitable, supportive, and sustainable use of existing resources and just and ecologically sustainable communities.

Reclaiming streets and using them in an inclusive and sustainable way can bring a significant paradigm shift in the governance of urban spaces towards co-governance of local resources that directly involves communities, urban planners, architects, and designers. Commoning practices can inform collaborative development at a local level (community level) as well as at a city level (policy making, urban planning). This can lead to the direct involvement of the community in the maintenance and design of spaces (urban ecology; co-design, etc.), by increasing ownership and responsibilities towards urban policies (e.g., homeless management, prostitution, drugs—the diseases of contemporary society). In cities characterized by centralized planning models and less state intervention due to increased economic and fiscal crisis, commoning practices can gradually gain more strength since they rely on sharing power, collective action and shared responsibility between the government and citizens. They can support community development and empowerment. The fact that more and more people initiate commoning practices in their efforts to tackle common problems in our societies is both a challenge and an opportunity for planners, designers, and city makers that are asked to both consider the emerging and increasing motivations raised by "commoning practices" and to develop processes that are more open, democratic, and based on the active involvement of local people.

Finally, commoning practices can also enrich the aesthetic value of the streets. During and after commoning practices, some physical elements of the streets may be modified directly or indirectly by participants' actions (modification in road uses, facade modifications such as murals) thus affecting the urban environment nearby the street or social practices in the whole city. The way in which commoning practices occur in streets and the way in which public spaces are used can create a special image of the neighbourhood and a particular urban atmosphere (Löfgren 2015), which can benefit the entire city.

Overall, commoning practices have a transformative power (Ryan 2013) as they propose alternative sets of social relations and practices—mutual support, care, negotiation, and experimentation—that have the capacity to change dynamics towards a shared management of resources.

References

Agyeman J, Bullard R, Evans B (2003) Just sustainabilities: development in an unequal world. Earthscan/MIT Press, London

Bingham-Hall J (2016) Future of cities: commoning and collective approaches to Urban space. Government Office for Science, London

Bollier D (2014) Think like a commoner: a short introduction to the life of the commons. New Society Publishers, Gabriola Island

Bollier D, Helfrich S (2012) The wealth of the commons: a world beyond market and state. Levellers Press, Amherst

Bollier D, Helfrich S (2019) Free, fair, and alive. The insurgent power of the commons. New Society Publishers, Canada

Bresnihan P, Byrne M (2015) Escape into the city: everyday practices of commoning and the production of Urban space in Dublin. Antipode 47(1):36–54

Centemeri L (2018) Commons and the new environmentalism of everyday life. alternative value practices and multispecies commoning in the permaculture movement. Rassegna Italiana di Sociologia 2:289–313

Chatterton P (2010) Seeking the Urban common: furthering the debate on spatial justice. City 14(6):625–628

De Angelis M (2017) Omnia Sunt communia: on the commons and the transformation to postcapitalism. Zed Books, London

Euler J (2018) Conceptualizing the commons: moving beyond the goods-based definition by introducing the social practices of commoning as vital determinant. Ecol Econ 143:10–16

Harvey D (2012) Rebel cities: from the right to the city to the urban revolution. Verso, London

Jacobs J (1961) The death and life of great American cities. Vintage Books, New York

Linebaugh P (2008) The magna carta manifesto. University of California Press, Berkeley

Löfgren O (2015) Sharing an atmosphere: spaces in urban commons. In: Borch C, Kornberger M (eds) Urban commons. Rethinking the city. Routledge, Oxon
Mitchell D (1995) The end of public space? people's park, definitions of the public, and democracy. Ann Assoc Am Geogr 85(1):108–133
Oliveira V (2016) Urban morphology: an introduction to the study of the physical form of cities. Springer, Switzerland
Ostrom E (1990) Governing the commons: the evolution of institutions for collective action. Cambridge University Press, New York
Pór G (2012) School of commoning. In: Bollier D, Helfrich S (ed) The wealth of the commons: a world beyond market and state. Levellers Press, Amherst
Rosol M (2018) Politics of Urban gardening. In: Ward K, et al (2018) The Routledge handbook on space of Urban politics. Routledge, London
Ryan AB (2013) The transformative capacity of the commons and commoning. Ir J Sociol 21(2):90–102. https://doi.org/10.7227/IJS.21.2.7
Secco L, Pisani E, Da Re R, Rogelja T, Burlando C, Vicentini K, Pettenella D, Masiero M, Miller D, Nijnjk M (2019) Towards a method of evaluating social innovation in forest-dependent rural communities: first suggestions from a science-stakeholder collaboration. Forest Policy Econ 104:9–22
Sofia M (2017) Public space, collective governance and the Urban Commons. The Urban Medi Lab. https://labgov.city/theurbanmedialab/public-space-collective-governance-and-the-urban-commons/
Sohn H, Kousoulas S, Bruyns G (2015) Introduction: commoning as differentiated publicness. FOOPRINT, pp 1–8
Stavrides S (2016) Common space: the city as commons. Zed Books, London
Stavrides S (2014) On Urban commoning: the city shapes institutions of sharing. In: Ferguson F (ed.) Make_Shift city: renegotiating the Urban commons. Jovis, Berlin
Stavrides S (2015) Common space as threshold space: Urban commoning in struggles to re-appropriate public space. FOOTPRINT

New Technologies and Public Spaces: Supporting Sustainable Urban Policies

Marichela Sepe

Abstract New technologies add value to public spaces if these are used to support the knowledge of a place and its use. The presence of wireless, multimedia support, apps and different ICT tools constitute elements, which can support the knowledge aspects of the place with its different characteristics and can be designed in a logic of integration with other infrastructure and networks in the city. Furthermore, the presence on social media, even if not exhaustive—as the presence of that public space as a background to a photo does not guarantee that it is a pleasant and successful space—offers, however, within a more comprehensive framework of information, data on the type and quantity of users and their perception of it. Indeed, new technologies in their different forms become more and more important tools to provide deeper knowledge of the place, participation, and to address sustainable urban policies. Starting from these premises, the aim of this work, carried out in the framework of the research project "PRIN2020 #20209F3A37", within the ISMed-CNR Unit with the author's responsibility and the related Sapienza Università di Roma-ISMed-CNR agreement, is to illustrate the positive influence of ICT tools on the use of both indoor and outdoor public spaces by: revitalizing them; increasing the possibilities of use as well as contributing to greater social cohesion; and supporting sustainable urban policies. By way of examples, two emblematic case studies of public spaces will be illustrated using an original and an ad hoc database.

Keywords New technologies · Sustainable policies · Public spaces · Urban design

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1 Introduction

New technologies can add value to public spaces if these are used to support the knowledge of a place and its use. The presence of wireless, multimedia support, apps and different ICT tools constitute elements, which can improve the knowledge aspect of the place in its different characteristics and can be designed in a logic of integration with other infrastructure and networks in the city. Indeed, these can become reasons for major use, socialization, sustainable economic growth and success [1, 2, 4, 5, 15].

Furthermore, the presence of public spaces on social media, even if not exhaustive—as the presence of that space as a background to a photo does not guarantee that it is a pleasant and successful site—offers, however, within a more comprehensive framework of information, data on the type and quantity of users and their perception of it (through, for example, the hashtags used, or comments left).

New technologies in their different forms, hence, become more and more important tools to provide deeper knowledge of the place, participation, and address sustainable urban policies in an inclusive perspective as well.

Accordingly, the NUA—New Urban Agenda adopted in Quito in 2016 during the Third Habitat Conference and which "represents a shared vision for a better and more sustainable future"—focuses attention on the aforementioned topics, as evidenced in the following related principles.

> We commit ourselves to promoting safe, inclusive, accessible, green and quality public spaces as drivers of social and economic development, in order to sustainably leverage their potential to generate increased social and economic value, including property value, and to facilitate business and public and private investments and livelihood opportunities for all.
>
> In this principle, the quality and flexibility of the public spaces are related to the presence of multifunctional, healthy and green areas, inclusivity, accessibility, social interaction and inclusion, dialogue between all people, and participation.
>
> We will promote capacity-development initiatives to empower and strengthen the skills and abilities of women and girls, children and youth, older persons and persons with disabilities, indigenous peoples and local communities, as well as persons in vulnerable situations, for shaping governance processes, engaging in dialogue, and promoting and protecting human rights and antidiscrimination, to ensure their effective participation in urban and territorial development decision making.
>
> In the above principle, the attention to the needs of women, girls, children, youth, older persons and persons with disabilities or in vulnerable situations is particularly outlined, in order to support specific attentions and policies to them.
>
> We will promote the development of national information and communications technology policies and e-government strategies, as well as citizen-centric digital governance tools, tapping into technological innovations, including capacity-development programmes, in order to make information and communications technologies accessible to the public, including women and girls, children and youth, persons with disabilities, older persons and persons in vulnerable situations, to enable them to develop and exercise civic responsibility, broadening participation and fostering responsible governance, as well as increasing efficiency. The use of digital platforms and tools, including geospatial information systems, will be encouraged to improve long-term integrated urban and territorial planning and design, land administration and management, and access to urban and metropolitan services [36].

In this latter principle, attention on ICT as a tool to improve responsible governance for all and access to urban and metropolitan services is specifically promoted.

Starting from these premises, the aim of this work carried out in the framework of the research project "PRIN2020 #20209F3A37", within the ISMed-CNR Unit with the author's responsibility and the related Sapienza Università di Roma-ISMed-CNR agreement, is to illustrate the positive influence of ICT on the use of public spaces by: revitalizing them, offering many kinds of technical facilities, making them more liveable; contributing to greater social cohesion; and supporting sustainable urban policies, also in the event of emergencies of different kinds. By way of examples, two suitable case studies of public spaces—with particular attention on new technologies—will be illustrated.

The case studies are selected from a series of 30 best practices [30, 31] of public space, which follow the principles of the Charter of Public Space [14]. The Charter was adopted during the second Biennial of Public Space held in Rome in May 2013 and presented during the events organized at the Quito Habitat 3 Conference in 2016, during which many principles were used for the New Urban Agenda discussion concerning quality public spaces.

To verify the validity of the Charter 10 years after its creation, 30 case studies were collected [30, 31, 35], and an ad hoc database was created to analyse them. The Charter is composed of 50 principles that are sort of guidelines for liveable and sustainable public spaces. The case studies that were selected for this paper are the Open Laboratory Project in Bologna and the NOI Techpark in Bolzano.

The paper is organized as follows: the second section is devoted to theoretical questions related to ICT and new *communities of flows*, the third section to the illustration of the original database, the fourth to case studies, and finally the fifth to observations and conclusions.

2 New Technologies and Communities of Flows

There is no clear distinction between different types of networks. Infrastructure networks are the physical subsystem of the city, the venous system that distributes flows for the survival of the socio-anthropic component and the urban system. These arise from project design and must ensure a satisfactory and efficient level of service to the urban community. These nets are material, not very flexible and highly vulnerable, due to their intrinsic rigidity. In many cases, the presence of the infrastructure marks the limit of the city [7, 8].

If, on the one hand, the effects of physical infrastructure are in some way predictable or at least attributable to comparable phenomena, it is different for virtual, social and cultural networks that open to increasingly large and uncontrollable ecosystems, with intersections and overlaps that mimic real relationships but give life to systems that are not easily controllable [13, 19].

Internet connections, if on one hand, make work relationships, social relationships, etc. easier, on the other hand distance relationships between places and people, creating new (non-geographical) distances [9].

Different infrastructure in the digital city has generated the root of what is now called the "intelligent city" or "smart city", in which technologies in their many forms are at the service of the city in order to both improve the quality of life of its users and to guarantee sustainability.

Research and practice in the field of infrastructure and urban virtualization, and not only, are today strongly oriented towards the use of smart technologies [4, 10, 11, 22]. The ability to control every action, service, desire, movement from a digital device has the aim of speeding up times and improving results. New spaces in contemporary metropolises are changing their place identity—that can be perceived by physically using the sites—in favour of an identity that can be quickly captured by a smartphone or tablet [26]. More and more sophisticated apps are offered to visitors and common users of places, creating accelerated visions of culture and services.

Furthermore, physical space has today become a counterpart of vital importance for digital existence: the use of networks has led to a different way of conceiving the participation of citizens in the construction process of the territory. Community hubs, network thinking and social media are some of the terms that indicate the current ways of relating to networks by communities [23–25].

Advanced technology infrastructures introduce a new exchange culture by creating new opportunities for interaction within settled communities. Through the innovative contribution of these infrastructures, forms of land use are being reorganized, creating contexts where social exchange replaces those formed over time. The processes are not easily identifiable because the signs that are formed do not always understand the transformations that are taking place.

The interaction between virtual communities and urban places can have different effects. Graham and Marvin [17] observe two elements in particular in this regard: the relationship modalities between virtual communities and the public sphere; the implications of the birth of entirely virtual cities. As Healey et al. [20] asserted "the physical city must be replaced with a virtual urbanity, a city of the mind created by telematics". "The hope of this new technological revolution is that it will provide the channels through which knowledge and information will be more democratic, dispersed due to the diversity of relational networks in urban regions". However, there is also the risk that virtual communities could lead to further urban fragmentation and a removal of sociality from urban places in favour of electronic networks and that: "ethnic groups will gather in their virtual communities, that libertarians speak only to other libertarians … inevitably, the effect will be to demolish local geographic communities and ultimately weaken the entire national community" [3].

Even if this happens, "the widespread adoption of such sophisticated electronic spaces could lead to a further intensification of the separation of the places of the space and blur the boundary between real and simulated, between public and private (…). It is difficult to speculate on the ways in which such changes will affect cities, but there seems to be no doubt that the elaboration of a whole complex of virtual realities within which considerable portions of the urban population will spend considerable chunks of time, it will alter the ways in which they approach and use the physical spaces of cities and the nature of social interactions"(Graham and Marvin, 2002).

Technologies are in fact restoring dignity to the "place" as a result of the interaction between space and sociality. For this purpose, elements of tangible and intangible heritage are put in place that can contribute to increasing the attractiveness of the city, creating an experiential vision of paths and parts of it. This vision is favoured by the presence of a quality urban environment and a creative class [12]. Smart experiential paths are an example of the use of ICT as tools capable of supporting knowledge of the place through multimedia and interactive devices.

Such virtual communities have the common goal of supporting specialized social groups often separated by geographical distance [16]. In fact, new information technologies allow the generation of networks in a very short time through which urban sociality can exchange information, participate in choices and express consent.

Managing the enormous amount of data coming from the network requires in this regard a revision of planning models and the tools these are implemented with, as well as the definition of new boundaries in order to create adequate practices and protocols to apply them. In this sense, new possibilities arise for territorial projects capable of being in line with the contemporary scenarios of flows and networks in places [7, 19, 23, 24].

The encounter between the different spaces of flows will result in a variety of environments, generating integrated platforms that will redesign connections, hierarchies and development opportunities [33, 34].

Indeed, a spatial configuration capable of favoring complex interconnection should perform multiple functions, namely: facilitate the exchange between the different modes of mobility, even soft; place new functions in infrastructural nodes; ensure the high quality of pedestrian, cycle, river and green paths, to facilitate the presence of more typically urban functions. Furthermore, the more strictly functional aspect should be adequately connected to the high symbolic and cultural quality of the spaces attached to infrastructure nodes, in order to create a sense of belonging and safeguard the identity of the places [27–29, 31, 32].

Blue, green, cycle, pedestrian, experiential, cultural, virtual and multimedia paths can overlap, intertwine and recombine and have the potential to create new mixed urbanities that are more liveable and sustainable.

In this perspective, the project of a place that wants to act as a generator of its cultural armour must be able to propose territorial devices that act on its metabolism by stimulating its social, economic, educational, health and landscape connective functions. In this new dimension, one of the most exciting challenges is design and planning based on the creative multi-dimension of development able to seize the opportunities of the alliance between heritage and creativity, heritage and innovation [6] and heritage and health.

3 Data Collection

To analyze the 30 case studies, and those which will be illustrated in this paper, the QPS-D@taC—Quality Public Space D@ta Collection was created. This is an original database [30, 31] constructed by collecting information, images and planimetries concerning the phases of design, realization, and management of public spaces. Information regarding the success of the spaces in question and their presence—where they are—on social media is also included. Data is collected by different sources, including information from the professionals or technicians who created the spaces, internet websites, bibliographical references, and on-site visits.

The first element to collect is the year of realization; although a project such as a public space is realized in the medium-long term, the year of realization indicates the moment in which it is inaugurated. If, as happened in some cases, the spaces were inaugurated in different phases (e.g., 2010–2013), these were indicated, giving the idea of the different steps in the realization of the sites. The second element is the planimetry of the project and relative images that detail the shape and/or the position of the public space within the surrounding territory.

The third element is the city where the space is located and its address. The fourth element is the measure of the surface area; these data together with its localization have the function to explain, the extent of the project work, and the consequent "urban weight" of the public space in the territory.

The fifth element to collect consists of identifying the institutions involved; these data are useful to comprehend if and what public entities are involved in the process of creating the space and if the private sector is involved. The presence of public entities clarifies the will of local administrations to realize a space that is public and for public use; the contribution of the private sector usually identifies the need for funds in the executive and/or management phases.

Funds are also useful data—the sixth element—which is connected to the previous one because it needs to indicate the whole amount—both public and private—used to realize the public space. Furthermore, in the database, it is indicated if the management cost was forecasted and the amount.

The presence of an urban planning project—the seventh element—, which is the general framework for the realization of a public space, is indicated, explaining if the public space is part of a greater regeneration project, or if the project only concerns the public space area in question. Accordingly, information concerning possible public concessions is reported to understand all the urban planning tools used to realize the public space. The names of the architects or urban designers are also reported if the project is realized by a private firm.

The eighth element consists of identifying the policies, which are carried out for the public space in question, and, as for the previous data, these may concern only the specific site or a wider area if the space has been realized in the framework of a broader regeneration project. The database can comprehend ad hoc policies—for long or short periods—adapted for specific needs, such as for the pandemic.

The ninth element concerns both the kind of uses and fruition of the space (Moriarty and Honnery 2008; Porteous 1977) [27]. This is important information that serves to identify the potential activities that are designed for the public space in question and what are those that are really carried out, and the kind and typology of access points.

These previous data give information regarding the success of the project (the tenth element). Here data concerning the presence of people, the organization of cultural events and the presence of public space on the social media are collected. In particular, data concerning the presence on social media, although not exhaustive, offer an indication—through the kind of hashtags, number of followers and likes, and numbers and kinds of comments—on the typology and quantity of users and on their perception of the site [18].

Finally, the database contains the main bibliographical and website references (elements 11–12) which constitute—together with the information provided by the technicians and professionals involved in different ways in the realization of the case in question—the sources of information on the different public space [30, 31].

4 Two Case Studies in Bologna and Bolzano

The best practices of public spaces that were chosen to verify the validity of the Charter of Public Space 10 years after its creation are based on seven categories, namely: waterfronts (in Pescara, Genova, San Benedetto del Tronto and Palermo), squares (in Catanzaro, Trieste, Catania, Palermo, Siena, Aosta, Perugia, and Termoli), gardens (in Rome and San Donà di Piave), parks (in Milan, Turin, Lecce and Cagliari), open-air transportation hubs (in Scandicci, Naples and Padua), nature paths (in Trento, the River Nera and Val di Sella) and projects on spaces in which the use of ICT tools support and improve different uses (in Bolzano and Bologna). The general framework that emerges from the 30 collected case studies shows different design, planning, cultural, geographical, social and financial factors that can determine the quality of a public space [30, 31].

As mentioned previously, the two case studies concern the Open Laboratory Project in Bologna and the NOI Techpark in Bolzano.

The first case study is the Open Laboratory Project realized between 2016 and 2018 in a 2000 m^2 surface in Bologna within an area located between Palazzo Re Enzo, Sala Borsa (Fig. 1), Palazzo D'Accursio and the former Galleria d'Accursio.

The Institution involved was the Municipality of Bologna and the funds were 3 million euro from the POR FESR [11]–2020—AXIS 6—devoted to *Attractive and participated cities involving the main cities of Emilia Romagna.*

This space was part of the framework of the redevelopment program approved by a municipal council resolution. Different kinds of policies were activated, namely: physical restoration and functional and technological ones. In the first case, the spaces were all connected to each other through a covered path obtained by rearranging the old underpasses and using the square in Sala Borsa and the courtyards of Palazzo

Fig. 1 Bologna, Sala della Borsa entrance (*Source* Marichela Sepe' archive)

d'Accursio. The new public space is a place of connection, contemporary, comfortable and usable in any climatic situation by citizens and tourists. In the second case, the containers were joined together through appropriately equipped spaces with a view to creating a single "open laboratory" devoted to the interactive use of cultural heritage and creative collaboration between citizens, the administration, associations and businesses.

The kind of uses are many, the basic idea is that this public space provides a meeting place and for socialization first of all, but also to a set of spaces for technical laboratories and meeting rooms.

The different Labs Spaces with the support of the ICT are in fact places well equipped and connected to each other, with a strong coordinated image. These are spaces—the gallery, boulevard, house, studio and atelier—suitable for welcoming the public. The aim is to make information and activities easily accessible and experiment with technologies and software, with tables for collaborative work and tools for presentations and sharing information, spaces to manage moments of aggregation and spaces for meetings and audio–video equipment for amplification and streaming of meetings and videoconferences.

In particular, the part called "The Atelier" is an educational and workspace that hosts group activities and where everyone can learn about changes to Bologna and become a sort of key player in imagining its evolution.

Using the interactive table, it is possible to plan solutions to transform public spaces in the city by combining words and images in an activity inspired by the game "Plus and Minus" by Bruno Munari. Furthermore, case studies of urban regeneration in Bologna, Italy, Europe and around the world are displayed on the walls with a database of materials to enrich the project design from a technical point of view to learn more about the regeneration of public spaces.

These data can also be accessed through BOforAll, a free and inclusive app that helps people discover Bologna's historical centre, with attention to people with physical, visual and auditory disabilities. The intention is to intertwine the production of innovative intangible services and the offer of consolidated cultural services, namely, the library, exhibition venues and cinemas.

There are many elements that testify to the success of the case study. The spaces are used frequently by people of all ages and abilities for different uses and, thanks to the covered path, these are also used on days with unfavourable weather conditions [37].

Furthermore, there is a wide presence on social media which concerns: Instagram page with 1224 followers, Facebook page with 9250 followers and Twitter page with 11,700 followers.

On these social media pages, most of the content is related to the activities of the Laboratories, which, with the help of new technologies, make knowledge of public space and its heritage more accessible and inclusive, supporting socialization across people of different ages.

The second public space project is NOI—Nature Of Innovation—Techpark, which was realized between 2015 and 2017 and inaugurated in 2017. NOI Techpark is located—with a surface of 120,000 m^2. (190,000 m^3)—in South Bolzano in the former metallurgical area "Montecatini", later known as "Alumix" (Fig. 2).

The property is public—owned by the Province of Bolzano—and the Institutions involved in the creation of the space were the Autonomous Province of Bolzano and BLS (Business Location Alto Adige), which then merged into IDM Sudtirol and now NOI spa.

The Institution involved in the space management is NOI spa, while as regards the funds, recovery, renovation and restoration of two processing plants and a building, construction of the new building and the underground garage as well as the realization of the indoor public spaces and part of the special furnishings had a total cost of 64,171,570 euro. These funds came from the Province of Bolzano and to a small extent from the ESF.

The urban planning tools of reference are the PUC—Urban Planning Municipal plan—Areas for supra-municipal collective facilities and the architectonic and urban design was realized by Chapman Taylor Italia (Milan) and Studio CLEAA (Claudio Lucchin e Architetti Associati, Bolzano), with Andrea Cattacin (Trento).

The policies that were activated include: strengthening the innovative potential of the area with the fundamental use of new technologies, supporting local companies in the field of research and development, intensifying international contacts in the South Tyrol economy to create job opportunities and attract highly qualified personnel. The NOI Techpark Südtirol/Alto Adige plays the key role of an innovation

Fig. 2 Bolzano, NOI Techpark, public space (*Source* NOI Techpark)

centre, capable of connecting small and large companies with start-ups and research institutes, offering space for the most advanced research and the most innovative companies connected to particularly attractive public spaces which play the role of collectors among the scientific laboratories.

There are different types of uses including researchers, students and companies who work closely together to create innovative solutions. To this end, the NOI Techpark provides them with laboratories and workshops equipped according to the most advanced standards. By taking advantage of the infrastructure offered the numerous innovative services and the public spaces companies join the NOI network and benefit from the exchange of knowledge and technologies between the research sector and the economic sector within an attractive and innovative environment created for all the people who work or live there. Companies also have the opportunity to rent laboratories and spaces for production use or to settle permanently within the technology park to create a place to work and socialize.

There are many elements that testify to the success of the case study. The hub is home to 25 Italian startups, 5 research centres, 30 companies and 20 laboratories. These companies include Huawei, Maccaferri, Grandi Salumifici Italiani, Leitner, while several laboratories have been installed at the disposal of companies and research institutes. The space works mainly on four thematic areas: Green, Food, ICT and Automation and Alpine Technologies. The area, not far from the city centre, has been transformed into an innovation district with research laboratories, a nursery, an outdoor arena for cultural events, a park, this is a space that has been returned to the city and its users which is still growing and will welcome new laboratories in the next 2 years—six other modules—and public spaces. Furthermore, the Techpark is fully usable and accessible to all people [38, 39]. The presence on social media is extensive and includes: Instagram #noitechpark (hashtag and place) with 4631 followers, Facebook US techpark (place and page) with 2802 followers and 2713 likes, and the #noitechpark hashtag on Twitter.

As testified by the use of this place by people and social media content, NOI has become a centre of both cultural and technological interest, which has improved socialization between people, researchers and companies thanks to the appeal of its environment made up of laboratories and public spaces and is well integrated in its social and urban tissue.

5 Observations and Conclusions

New technologies—as demonstrated by the two case studies—give new possibility of use within public spaces—both indoor and outdoor.

Indeed, the use of public spaces should be reconsidered in this direction. Access to networks in squares, streets, parks and the possibility to use multimedia tools in both indoor and outdoor space have made it possible to increase the appeal of places. Recent studies relating to the influence of the Internet in indoor and outdoor public spaces [21] show how it has expanded their use by revitalizing and repopulating them, improving their security and also contributing to greater social cohesion. The presence of multimedia content is a further element that extends the use of public spaces, creating the possibility to learn about the history of places, but also about the available services and equipment, or giving the opportunity to respond with a message to questions or comments placed on ICT supports, helping to increase interaction between users and places. Furthermore, being able to have access to multiple types of information favours possible exchanges of ideas among the users of the places, affirming the public function of the space.

The two case studies that were illustrated were realized in this perspective, namely, to facilitate knowledge with the use of ICT, creating or enhancing public spaces, improving social cohesion and finally the economy.

In the case of Bologna, the different Labs Spaces with the support of the ICT are places specially equipped and connected to each other with a strong coordinated image. The gallery, boulevard, house, studio and atelier welcome people with the aim of making information and activities easily accessible and experimenting with technologies and software such as BOforAll, which is an inclusive app that helps people to discover Bologna's historical centre, with attention to people with physical, visual, or auditory disabilities.

In the Bolzano case, the presence of many laboratories and research centres in an attractive environment made of contemporary open-air public spaces has improved its use, becoming a centre of both cultural and technological interest which has increased socialization between people, researchers and companies thanks to the peculiarity of the site constituted by a "space for science" and "spaces for free time", that are well integrated in Bolzano and its provincial, social and urban tissue.

The database used to collect the data related to the case studies was very useful in this sense because it identified the presence of public institutions at different levels, the policies and uses and the success of the new public spaces in which the use of ICT is an important factor.

Although in the COVID-19 period of major social restrictions, those spaces were used less they are reference spaces in their cities for socialization and activities, and the use of ICT has facilitated the exchange of information of many different kinds among all people. Indeed, these places are easily accessible by people at different hours improving the sense of belonging to them.

The lesson to be learned from these two cases is that socialization, knowledge as well as the economy can mutually be reinforced if suitable public spaces and uses of new technologies are integrated.

Future steps in this study concern an update to the Charter of Public Space which will include new principles related to the use of ICT to improve the quality of public spaces specifically devoted to knowledge and research, and the suitable use of social media to share the degree of satisfaction of a place, or to communicate possible unexpected risks and the relative measures to follow.

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References

1. Amin A, Graham S (1998) Cities of connection and disconnection. In: Allen J, Massey D, Pryke M (eds) Understanding cities: movement and settlement. Open University Press, USA
2. Anderson Benedict R (1991) Imagined communities: reflections on the origin and spread of nationalism. Verso, London
3. Brown J, Barber A (2012) Social infrastructure and sustainable urban communities. Proc Inst Civil Eng-Eng Sustain 165(1):99–109
4. Campbell T (2012) Beyond smart cities. How cities network, learn, and innovate. Earthscan Publications, London
5. Carmona M, Heath T, Oc T, Tiesdell S (2010) Public places-Urban spaces. Architectural Press, Oxford
6. Carta M (2014) Reimagining urbanism. List Lab, Trento
7. Castells M (1989) The informational city. Blackwell, Oxford
8. Clementi A (1997) L'ambiguo impero delle reti. In: Desideri P, Ilardi M (eds) Attraversamenti. I nuovi territori dello spazio pubblico. Costan & Nolan, Genova-Milano
9. Desideri P (ed) (2001) Excity. Spazi esterni e reti della nuova metropoli. Meltemi, Roma
10. Duany A, Speck J, Lydon M (2010) The smart growth manual. McGraw-Hill, New York
11. de Waal M (2014) The city as interface. How digital media are changing the city. NAI010 Publishers, Rotterdam
12. Florida R (2002) The rise of the creative class: and how it's transforming work, leisure, community and everyday life. Perseus Book Group, New York
13. Frederick HH (1993) Global communication and international relations. Wadsworth, Belmont, CA
14. Garau P, Lancerin L, Sepe M (2015) The charter of public space. LiST, Trento
15. Gehl J (2010) Cities for people. Island Press, Washington

16. Graham S, Marvin S (2001) Splintering urbanism: networked infrastructures, technological mobilities and the urban condition. Routledge, London, New York
17. Graham S, Marvin S (2002) Città e comunicazione. Baskerville, Bologna
18. Huai S, Van de Voorde T (2022) Which environmental features contribute to positive and negative perceptions of urban parks? A cross-cultural comparison using online reviews and Natural Language Processing methods. Landsc Urban Plan 218
19. Hall P, Preston P (1988) The carrier wave: new information technology and the geography of innovation 1846–2003. Unwin Hyman, London
20. Healey P, Cameron S, Davoudi S, Graham S, Madanipour A (eds) (1995) Managing cities: the new urban context. Wiley, Oxford
21. Hampton KN, Livio O, Sessions LF (2010) The social life of wireless urban spaces: Internet use, social networks, and the public realm. J Commun 60(4):701–722
22. Hatzelhoffer L, Humboldt K, Lobeck M, Wiegandt C (ed) (2012) Smart city in practice. Converting innovative ideas into reality. JOVIS Verlag, Berlin
23. Keith NH, Livio O, Goulet L (2010) The social life of wireless urban spaces: Internet use, social networks, and the public realm. J Commun 60:701–722
24. Kaika M, Swyngedouw E (2010) The urbanization of nature. Great promises, impasse, and new beginnings. In: Bridge G, Watson S (eds) New companion to Urban studies. Wiley/Blackwell, Oxford
25. Kaika M, Swyngedouw E (2000) Fetishizing the modern city: the phantasmagoria of urban technological networks. Int J Urban Reg Res 24:120–138
26. Ratti C (2014) Architettura open source. Einaudi, Torino
27. Sepe M (2013) Planning and place in the city. Mapping place identity London. Routledge, New York
28. Sepe M (2015a) Reti di luoghi, paesaggi delle tecnologie e nuove connessioni. Crios 10(2):69–80
29. Sepe M (2015b) Improving sustainable enhancement of cultural heritage: smart placemaking for experiential paths in Pompeii. Int J Sustain Dev Plan 10(5):713–733
30. Sepe M (2020a) Spazi pubblici nella città contemporanea. Inu Edizioni, Roma
31. Sepe M (2020b) Regenerating places sustainably: the healthy Urban design. Int J Sustain Dev Plan 15(1):14–27
32. Sepe M (2022) Designing healthy and liveable cities. Creating sustainable urban regeneration. Routledge, London and New York
33. Sokolowski JA, Banks CM (2009) Principles of modeling and simulation. Wiley, Hoboken, NJ
34. Swyngedouw E (1993) Communication, mobility and the struggle for power over space. In: Giannopoulos G, Gillespie A (eds) Transport and communications in the New Europe. Belhaven, London
35. UN Habitat (2013) Global public space toolkit from global principles to local policies and practice. United Nations Human Settlements Programme, Nairobi
36. http://habitat3.org/wp-content/uploads/NUA-English.pdf
37. http://www.fondazioneinnovazioneurbana.it
38. https://noi.bz.it/it. Accessed 2 July 2023
39. https://www.wired.it/economia. Accessed 2 July 2023

Augmented Nature-Based Solutions: A Possible Taxonomy of Technologies "in" and "for" Urban Greening Strategies

Israa Mahmoud, Eugenio Morello, Adriano Bisello, and Dionysia Kolokotsa

Abstract The conceptualization and application of nature-based solutions (NBS) in the practice of planning and projects on urban and architectural scales have reached a level of maturity in the last 10 years, thanks to a strong push from European policies and funding for European projects and evidence from scientific literature. However, a systemic insight into the role of technology in supporting the spread of NBS has not yet been developed. The role of technology is understood here as fundamental to the very core concept of NBS, i.e., engineering solutions that integrate technological aspects to effectively increase nature's potential. The authors, therefore, propose an investigation into the various opportunities offered by technology integrated "**into**" greenery and used "**for**" promoting greenery, based on the experience of two European Horizon 2020 projects, CLEVER Cities and VARCITIES, and from the application cases presented during the dedicated track at the SSPCR 2022 conference.

Keywords Nature-based solutions · Green technologies · Co-monitoring · Citizen science · Citizen participation · Internet of nature

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1 Introduction

The discipline of implementing Nature-Based Solutions (NBS) at architectural, urban planning, and landscape levels is supported by numerous experiences and several European projects and case studies (Bulkeley 2020; European Commission 2020). The concept of NBS is based on green or blue engineering solutions that replace more traditional gray solutions. The presence of technology in NBS is, therefore intrinsic and fundamental, no matter how low or high-tech this technology is (Andersson et al. 2022). Technology is directly embedded in NBS or applied as an essential component of all technological NBS generally. With NBS, nature is, in fact, "augmented" using technology to improve performance and increase the co-benefits of nature itself in the built environment.

Recent literature on NBS shows a strong interest in possible demonstrations and applications with a technologically embedded approach towards better solutions implementation (Tsekeri et al. 2022; Scheuer et al. 2022; Wellmann et al. 2022). Lately, technologies related to the possible integration of NBS into urban planning are coming to light towards execution scopes in order to increase the environmental performance and social impact of NBS.

However, a systemic insight into the role of technology in supporting the spread of NBS has not yet been conducted (Ahlborg et al. 2019). In this paper, a new proposed NBS taxonomy based on the technology-nature relationship is presented, supported by an extensive overview of the implementation of various technologies within case-study settings of NBS in urban greening strategies and European projects.

The proposed taxonomy is discussed from a twofold perspective: technology embedded "**in**" green, and technology "**for**" supporting the flourishing of green in the built environment, i.e., applied externally to NBS. In particular, the following explorations around technology in and for NBS are significant:

1. **Technology in Green**: Embedding technologies inside NBS aims at increasing its environmental performance and social impact; for instance, environmental sensors measuring the health of nature and linked environmental aspects in the surroundings; urban displays and communication interfaces for people to communicate relevant messages; sensors for co-monitoring campaigns as part of citizen science activities around urban greening activities.
2. **Technology for Green**: outside and beyond NBS per se, technologies can be applied to enhance the widespread presence and impact of NBS in the built environment; for instance, ICT can be used to engage citizens in co-producing (co-design, co-implementation activities) and taking care of green spaces (co-maintenance, co-monitoring activities), thus generating a stronger sense of belonging and social bond within communities, with emphasis on the inclusion of marginalized and vulnerable groups. Moreover, mapping technologies such as remote sensing and LiDAR applied to urban green, can support monitoring overall progress towards greener cities (Ahmed et al. 2019; Ramzan et al. 2021), contributing to assessing the global targets of the UN 2030 Agenda at the local scale (e.g., localizing SDGs in cities), see (Breuer et al. 2022; Mahmoud et al. 2022).

2 Context: European Projects and a Dedicated Conference Track

This paper originates from an investigation into several applications of NBS in real settings, where we looked explicitly for scientific methods and innovative products and services to enhance the potential of NBS in urban contexts while using technology. An initial literature review on the analysis of "Technology" and "Nature-based Solutions" was carried out in Scopus,[1] whereas 259 articles and scientific products have resulted more prominent since 2016, with a noticeable peak in the years 2021 and 2022.

In addition, our sampling was increased by the session at the Smart and Sustainable Planning for Cities and Regions Conference[2] (SSPCR 2022) held in July 2022, where the contributions and discussions offered "food for thought" for the content of this paper. The research questions are related to the main session topic on Augmented Nature-based solutions in urban planning and embedded technologies to improve NBS performance and foster social inclusion in urban greening strategies. In contrast, scientific contributions came from different countries, mainly: Italy, Spain, Austria, and Germany. Lastly, we relied on the ongoing application of two European Projects funded by the Horizon 2020 Programme to consolidate the proposed taxonomy, namely CLEVER Cities and VARCITIES, in which the authors are currently involved in.

The CLEVER Cities[3] project (June 2018–September 2023) aims to co-create, co-design, co-implement, and co-manage locally tailored NBS to deliver tangible social, environmental, and economic improvements for urban regeneration. It gathers 36 international partners and involves three front-runner cities (Hamburg, Germany, London, United Kingdom, and Milan, Italy) and six fellow cities (Madrid, Larissa, Belgrade, Malmo, Quito, Sfantu Gheorghe). CLEVER Cities applies a place-based approach, starting with key urban regeneration challenges and employs strong local partner clusters to foster sustainable and socially inclusive urban regeneration locally, in Europe, and globally. The CLEVER Cities project co-creates, co-designs, co-implements, and co-manages locally tailored NBS to deliver tangible social, environmental, and economic improvements for large-scale urban regeneration processes. Particular attention in the implementation of NBS within CLEVER Cities is given to shared governance mechanisms and collaborative pathways of co-creation aimed at advancing the cities' adaptation to a more bottom-up approach to urban planning (Borsboom-Van Beurden et al. 2023; Bradley et al. 2022; Mahmoud and Morello 2021).

[1] https://www.scopus.com/results/results.uri?sort=plf-f&src=s&sid=197ad86419648a8651cca486de4deeeb&sot=a&sdt=a&sl=56&s=TITLE-ABS-KEY%28%22technology%22+AND+%22nature-based+solutions%22%29&origin=searchadvanced&editSaveSearch=&txGid=c1ef373d55fd60c8742f163143abbd87.

[2] https://www.sspcr.eurac.edu/session-augmented-nature-based-solutions-or-cities/.

[3] https://cordis.europa.eu/project/id/776604.

The VARCITIES project[4] (September 2020–February 2025) bridges the NBS approach traditionally characterized by low-tech solutions devoted to enhancing environmental quality with high-tech devices more familiar with the smart city approach to increase the health and well-being of citizens around Europe. It gathers 28 international partners and involves seven pilot cities (Castelfranco Veneto—Italy, Gzira—Malta, Skellefteå—Sweden, Novo Mesto—Slovenia, Dundalk—Ireland, Chania—Greece and Leuven—Belgium) willing to test and implement a series of innovative initiatives on urban green/public spaces. Digitally advanced NBS are therefore implemented through a co-design, co-creation, and co-implementation process, bearing in mind local stakeholders' social and cultural perspectives. Urban spaces are envisioned as people-centered areas that support creativity, inclusivity, health, and happiness for citizens.

3 Technology "in" Green and Technology "for" Green: The Proposal for a New Taxonomy for Augmented Nature-Based Solutions

Initial understanding of the technology "**in**" green urban strategies topic includes different types of sensors that could be used to measure the NBS health status or remote sensing methods to enhance ecosystem services delivery in people's everyday lives (Li and Nassauer 2021). Gudowsky and Peissl (2016, pp. 5–6) highlight the importance of technology in corresponding citizens' visions and social needs by using it as a support and catalyst for change in public engagement processes. In the meantime, Maes and Jacobs (2017, p. 123) call for the need to use NBS with low-technological impact to increase the social empowerment of local communities.

Meanwhile, understanding of the technology "**for**" green urban strategies topic incorporates all the technological support to enhance NBS functionality, durability, and diffusion (Dick et al. 2020). Among others, technologies for green include the use of digital platforms and efficient software to visualize, analyze, and integrate data for NBS deployment in urban planning, such as drones and GIS modeling and mapping methods (Rakha et al. 2021). For instance, recent developments in technology and integration into the human-built environment could help develop the redesign of certain NBS and green infrastructures while increasing their co-benefits and improving ecosystem services (O'Hogain and McCarton 2018). This broad concept is related to the diversity in scales of implemented NBS. Nonetheless, some scholars argue that even "low-tech" or "no-tech" green—also considered as traditional urban greening measures—would still need data elaboration, especially if it relates to vegetation performance against natural and water management capacities to enhance the possibility for urban planners, architects, and landscape designers to reclaim valuable urban spaces correctly (Snep et al. 2020).

[4] https://cordis.europa.eu/project/id/869505.

Based on this ideation, the resulting taxonomy for Augmented NBS with technologies "**in**" and "**for**" green is divided into two main subcategories: sensing with technologies and citizen engagement methods. Other technological aspects are also related to NBS, like structural technologies that sustain and support nature. However, in this taxonomy, we only focus on those technologies that help to give nature a voice and enhance it through sensors or collaboration with people.

On one side, sensing "**in**" green refers to all the technologies directly embedded in NBS to detect the health of natural elements or surrounding environmental aspects (e.g., air, water, soil). On the contrary, sensing "**for**" refers to all the technologies that are situated outside the NBS, hence remote sensing devices (mounted on drones, satellites to collect LiDAR, thermal data, and similar technology) to monitor the health of natural NBS performance.

On the other side, citizen engagement "**in**" green refers to technologies placed inside or around NBS that directly involve human activities in detecting, mapping, and assessing the direct social impact of people on nature or the environmental impact of nature on people. Detaching ourselves from NBS, the engagement of people "**for**" green, i.e., to promote urban nature, is undoubtedly very vast and can take place in a variety of ways: from low-cost technologies, such as participation models and protocols (from co-design and co-maintenance) of greenery, to more advanced technologies to facilitate collaboration in the creation of NBS (digital fabrication, applications and social media, wearable technologies, etc.).

A further category that structures the taxonomy refers to the phase in which the technologies are employed, i.e., in the planning, design, construction or monitoring and evaluation (M&E) of NBS. This categorization is important to understand the planning phase of technologies themselves and the duration of their use in relation to NBS. The last category refers to the low-tech or high-tech level of technology as considered its readiness level.

Table 1 summarizes the above-mentioned categories, enriched with references to tangible examples from research and practice to emphasize the importance of technology in different phases of urban planning.

Table 1 Taxonomy of Augmented NBS illustrating technologies "**in**" and "**for**" green with practical examples and throughout urban planning and management phases coupled with technology readiness level

Possible Taxonomy for NBS implementations and examples			Phases of urban planning and management			Technology readiness level	
Technology in Green		**Examples**	**Analysis**	**Co-design**	**M&E**	**High tech**	**Low tech**
Structural technology	3D printed hardware	CO-MIDA: [a] 3D vertical gardens hosting plants		x	x	x	
Sensing	Sensors to monitor water content and humidity	VARCITIES: humidity and air quality, water, and snow level	x	x	x	x	
	Sensors for weather micro-climate and noise	VARCITIES: monitored by static/bike mounted/rover mounted sensors	x		x	x	
	Sensors for measuring the production of biological photovoltaics	CO-MIDA: [a] Bio-Photovoltaic System producing energy from bacteria	x		x	x	
	Wearable for plants	(Li et al. 2021): monitoring of plant stresses via chemiresistive profiling of leaf volatiles	x		x	x	
Technology for Green		**Examples**	**Analysis**	**Co-design**	**M&E**	**High tech**	**Low tech**
Remote sensing	GIS and LiDAR	RENATURE, VARCITIES: mapping vegetation and vegetation health	x	x	x		
	Drones for ecosystem services	VARCITIES Green modelling and mapping	x		x	x	
	Platforms for digitalization	Nature Quant: [b] Nature Score	x		x	x	

(continued)

Table 1 (continued)

Possible Taxonomy for NBS implementations and examples			Phases of urban planning and management			Technology readiness level	
Technology in Green		**Examples**	**Analysis**	**Co-design**	**M&E**	**High tech**	**Low tech**
		VARCITIES: Health and Well-being online platform	x		x	x	
	Sensors embedded in urban furniture and digital displays	Participate Melbourne: [c] social spaces and benches	x		x	x	
		VARCITIES: interactive totem with touch screen and multiple services					
		VARCITIES: smart benches					
Citizen engagement	Mobile applications	VARCITIES: Planet App		x	x		x
	Augmented Reality, Virtual Reality	VARCITIES: Wearables	x	x		x	
	Protocols of (digital) citizen engagement	VARCITIES: Gamification	x	x	x	x	
		CLEVER Cities: DIPAS	x	x	x	x	
		CLEVER Cities: Co-mapping urban NBS contest	x		x	x	
		VARCITIES: NBS impact appreciation, SROI calculation	x	x	x	x	
	Social media and smart devices	Nature Quant: [d] Nature doses		x	x	x	
		I Naturalist [e]	x		x	x	

(continued)

Table 1 (continued)

Possible Taxonomy for NBS implementations and examples			Phases of urban planning and management			Technology readiness level	
Technology in Green		**Examples**	**Analysis**	**Co-design**	**M&E**	**High tech**	**Low tech**
	Biodiversity mapping	CLEVER Cities: butterfly co-mapping by citizens		x	x		x
		VARCITIES: Bird species mapping	x		x		x
	NBS impact	CLEVER Cities: Social monitoring protocols	x		x		x

Source The authors

Legend: x is applicable

[a] https://iaac.net/project/co-mida-en/

[b] https://www.naturequant.com/naturescore/

[c] https://participate.melbourne.vic.gov.au/emerging-tech-testbed/social-spaces

[d] https://www.naturequant.com/naturedose/

[e] https://www.inaturalist.org/

4 Case Study and Applications from Two European Projects: VARCITIES and CLEVER Cities

Based on the above-mentioned taxonomy, we can report some examples that use similar technologies to evaluate NBS performance while using technology "in" green and "for" green.

4.1 VARCITIES Project

For instance, within the VARCITIES project, almost all demos and several partners are engaged in testing and developing technologies to achieve multiple purposes related to NBS.

Concerning the technology "in" green, it is worth mentioning that some municipalities have shown interest in exploring this concept further, moving towards a phygital solution, where the digital advanced content is made available to citizens and visitors through a physical installation. The city of Castelfranco Veneto is discussing with the project partner Eurac for the possible implementation of a totem equipped with an LCD touchscreen and audio system to be placed nearby the demo site of the historical garden of Villa Revedin Bolasco. The totem would make the activity of the VARCITIES project recognizable to citizens. For example, the explanation of scientific experiments conducted by the University of Padova on perceived restorativeness and benefits associated with exposure to nature in a garden (Sella et al. 2023) or effects of the landscape related to physiological and environmental parameters (Pirotti et al. 2022) would be accessible to non-experts and thus contribute to sharing the main results with adults and children. It would also serve cyclists and provide a charging point for smartphones and e-bikes, encouraging sustainable tourism and access to digital services. Moreover, it would show data coming from the H&WB platform (described in the next paragraph), adjusted for a better user experience considering the different framework conditions (larger screen, open-air location, specificity of the site), integrated with local info on touristic amenities and activities, and possible additional services or gamification tools. Similar installations have been already tested in smart city projects, e.g., the Sinfonia project in Bolzano—IT, see Grilli et al. (2018), but so far have never been conceived to interact with NBS or activities.

All pilot cities in VARCITIES are going to equip the demo sites with a large variety of IoT sensors, including wearable ones, according to the specific aim of some scientific experiments or the intention to monitor and report local environmental characteristics or users' habits and performance. For example, in the historical garden of Villa Revedin Bolasco the University of Padova (department of Agroforestry) installed several sensors to monitor microclimate conditions in various places in the garden and equipped a small, unmanned vehicle (a so-called rover) operated either by remote control or by an integrated GNSS system to gather data on the microclimate condition related to specific places in the garden. They also used a multispectral camera or portable sensor for vegetation index estimation and terrestrial laser scanning of "healthy areas" for 3D point cloud generation and AR/VR. Some benches have been turned into "smart" ones able to record the number of users sitting there and provide data on the effectiveness of their positioning along pedestrian paths.

Within the research and development activities granted by the project, the partner Sensedge is providing some demos with an advanced version of its "Senstick", a LoRaWAN sensor designed to generate reliable and quality data in harsh indoor and outdoor environments. The Senstick already includes sensors' functionalities such as environmental parameters (air temperature, relative humidity, and pressure), solid parameters (temperature, moisture). In VARCITIES, further evolution of the Senstick will support researchers and public administrations to understand and monitor thermal comfort in cities better. Another industrial partner Cyclopolis in Greece is developing and testing an innovative sensor to be mounted on any bicycle and able to monitor the air quality during movement from one location to another and relate it to the vehicle's position. Measured parameters include Particulate Matter (PM) sized 1, 2.5, and 10 μm, as well as temperature and humidity, while a GPS tracks the location.

Finally, in the demo case of Gzira, Malta which consists of greening and the social improvement of small public spaces along today's busy streets, a citizen science campaign is taking place that involves residents in measuring and reporting air quality and wind using low-cost sensors.

Regarding the second macro category of this framework technology “for” green; a so-called Health and Well-being (H&WB) platform is going to be designed and implemented by IES. The H&WB platform will be a visualization and management tool, a nature-focused digital twin to show KPIs and live and collected data in suitable and engaging ways to different STKs through specific dashboards. It will be developed using previous experience and iPIM and iCIM cloud-based tools provided by the project partner IES. 3D models of each pilot city will be accessible on the internet. The aim is to provide the final information to be published on the platform that is understandable and engaging for everyone by maximizing interaction and usability.

The project partner DEKKA is also developing an augmented reality platform to further engage citizens by placing digital elements in physical demo spaces and enhancing the visitor experience. Visitors can use it in combination with holovision glasses and enter an innovative and rewarding user experience.

Again, in the Castelfranco Veneto pilot scheme, additional wearable sensors have also been used by volunteers involved in physiological experiments designed by the Neural science department at the University of Padova to monitor and track the changes in the brain activity of visitors and relate them to various positions in the garden, microclimate parameters and aesthetic characteristics (eye-tracker glasses and portable electroencephalogram). Moreover, some smartphones with GPS and accelerometers are available to vulnerable visitors that are also equipped with a special app designed to provide real-time information on their position in the garden and request assistance on request or automatically in the event of tripping.

Alongside the development of scientific studies, EURAC engaged citizens and stakeholders in some remote and in-person evaluation activities related to the perception of societal value delivered by the foreseen execution of such innovative initiatives: social return on investment calculation in the Castelfranco Veneto choice experiment and willingness to pay elicitation in Gzira.

4.2 CLEVER Cities Project

CLEVER Cities, on the other hand, is an EU-funded project that did not rely so much on the technological components in its initial phase of co-creation planning and setting up of an urban innovation partnership (see Mahmoud and Morello 2021). Nonetheless, the co-design and co-monitoring phases have made extensive use of technological devices to enhance green spaces to focus on citizen engagement and co-monitoring processes, in particular e-participation techniques boosted by the COVID-19 pandemic.

Technology “**in**” green was mainly carried out during the environmental monitoring phases of the project lifetime started in 2021 in two living labs in Milan (Mahmoud and Morello 2023). Technological aspects were employed in order to help the co-monitoring of NBS environmental performance starting in 2022. In one of the urban living labs in Milan—IT, the so-called CLEVER Action Lab 1 aimed at diffusing green roofs and walls city wide, sensors in a two-story green wall of a public transport company ATM-owned depot building (via Giambellino 121) were used to monitor pollutants detection on leaves (ongoing) as well as for irrigation control of plants through the irrigation system. In another example in Milan, the CLEVER Action Lab 3, a public space adjacent to the new Tibaldi-Bocconi train station thermal camera drone flights helped to map the land surface temperature of the site prior to and after greening interventions implementation.

Meanwhile, technology "**for**" green was extensively used throughout the co-designing phase of the project. For instance, in the three living labs in Milan, the use of e-participation in all co-creation phases was widely used through digital meetings, interactive digital boards, and interface repositories. In addition, digital boards and online surveys supported co-monitoring activities and guaranteed continuity and willingness to participate in the co-creation process (Mahmoud and Morello 2018). Specifically, technology was used for data collection as well as in a repository hub to monitor and evaluate the social impact of NBS on local communities using online questionnaires distributed via QR codes and newsletters (Mahmoud et al. 2021).

Another example is the DIPAS *Digitales Partizipation system*, an e-participation and decision-making support system was implemented in the municipality of Hamburg, Germany (Arlati et al. 2021). Moreover, in Milan, a digital archive was collaboratively built thanks to a public call launched by the municipality in 2022 to award the best green roof and green wall solutions. "*Premia il tuo verde*" (translated: Reward your Green) became an online collaborative mapping experience that helped the city to detect the best practices of green roofs and walls around the city.

5 Discussion and Conclusions

In this paper, we propose a taxonomy to organize and frame how NBS improve their environmental performance and social impact through technology. We, therefore, introduced the concept of "Augmented NBS" to highlight technological support in and around green measures. This technological support can take the form directly on NBS or externally to it. Research projects' experiments and products on the market already show a rich variety of solutions, mostly adopting high-tech solutions as reported in Table 1 as well. An overview of these augmented NBS opens up a series of theoretical, ethical, and practical reflections on the use of technology in nature, thus posing new challenges in the triangulation of the relationship between human, nature, and technology.

"Tech-assisted NBS" or "smart green infrastructure" is becoming trend in a growing market that focuses on combining green and high-tech solutions, and the ambition towards the combined use of natural elements and innovative technological solutions challenges cities to rethink their governance structures and practices, calling for integrated approaches and the mobilization of competencies and skills across institutional sectors (Bisello et al. 2022). Numerous examples are already on the market for outdoor and indoor NBS and products. Embedding sensors in green infrastructure, according to the concept of Internet of Nature (IoN) proposed by

Galle (2019), is adding a layer of complexity to the materialization of the digital world or, on the contrary, to the digitalization of living systems. For instance, there are many examples of capillary and widespread applications of sensors in forests (Internet of Trees, IoTr), to monitor the spread of fires, drought, and the health of trees. Hence, "technological prostheses" applied to green solutions allow us to take care of nature with greater attention and effectiveness. Technology, therefore, supports the diffusion of NBS, often criticized for their maintenance costs, given that they are living and constantly evolving solutions, unlike corresponding gray solutions. Robots for the automated maintenance of vertical and horizontal green surfaces and systems to monitor the water and humidity content of plants and soil using sensors or thermal imaging cameras are already widely used examples that testify to the mature hybridization between technology and nature. However, all this smartness is not regulated and there are no shared protocols for the collection and transmission of data collected from the plant world. This aspect opens up a debate linked to the ethical aspects of exploiting nature and to the rights of nature itself in terms of protection and treatment of data produced through the IoN. Going further, nature can enhance the production of energy, opening up important and promising perspectives for research and development. Energy production through nature like bio-photovoltaic modules is the latest frontier of technology integrated with living organisms. Again, ethical questions are even more relevant in this case.

On the other hand, we have citizens and their willingness to protect and enhance nature, especially in urban areas. In this relationship to nature mediated by technology, awareness about nature's needs and impact is increased. Co-Diverse technologies can be deployed to facilitate participation and e-participation around nature and NBS. A closer and deeper human-nature relationship is enabled through digital (ubiquitous and connected) technology, which gives nature a voice and makes its needs visible to all. Digital technologies support improvements to this relationship in many ways, mainly increasing awareness of nature, shared governance, and democracy around nature and a sense of belonging and caring for nature. Firstly, Augmented Reality and Virtual Reality tools mounted on mobile or wearable devices help to make the invisible visible, represent nature and NBS in the current state or anticipate future urban greening scenarios and support monitoring, evaluation, and decision-making as part of design and co-design activities. Secondly, digital applications are excellent tools for building loyalty and establishing a caring relationship with nature by monitoring its health and state of conservation. In some cases, apps even initiate a dialogue between people and plants which transmit their state of health as recorded by the sensors. Finally, low-tech participation protocols can facilitate the inclusion of nature and NBS as stakeholders. For instance, nature enters decision-making processes by right, through different tools, e.g., role-playing and immersion in nature, or figures enlisted with the task of acting as guarantors of nature itself. It is, therefore, crucial to sensitize people to understand the multiple benefits (Zilio et al. 2022) related to these innovative NBS solutions and to translate them into values (societal, ecological, governance, and economic ones).

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References

Ahlborg H, Ruiz-Mercado I, Molander S, Masera O (2019) Bringing technology into social-ecological systems research—motivations for a socio-technical-ecological systems approach. Sustainability (Switzerland) 11(7):1–23. https://doi.org/10.3390/su11072009

Ahmed A, Ibrahim A, Hussein S (2019) Detection of palm tree pests using thermal imaging: a review. In: Hassanien AE (ed) Machine learning paradigms: theory and application. Springer International Publishing, pp 253–270. https://doi.org/10.1007/978-3-030-02357-7_12

Andersson E, Haase D, Kronenberg J, Langemeyer J, Mascarenhas A, Wolff M, Elmqvist T (2022) Based on nature, enabled by social-ecological-technological context: deriving benefit from urban green and blue infrastructure. Ecol Soc 27(4):art18. https://doi.org/10.5751/ES-13580-270418

Arlati A, Rödl A, Kanjaria-Christian S, Knieling J (2021) Stakeholder participation in the planning and design of nature-based solutions. Insights from CLEVER cities project in Hamburg. Sustainability 13(5):2572. https://doi.org/10.3390/su13052572

Bisello A, D'Alonzo V, Croce S, Zilio S, Segata A, Borsari A, Rompaey SV, Goni E, Micallef D, Calleja K, Quacinella D, Haarstad H, Dewagtere M, Gramberger M, Al-banis V (2022) D3.5: guidelines for sketching of solutions. https://varcities.eu/resources/deliverables/

Borsboom-Van Beurden J, Bisello A, Vettorato D, Vacha T (2023) Systemic changes in governance equipping local governments for realising climate-neutral and smart cities. https://smart-cities-marketplace.ec.europa.eu/insights/publications/systemic-changes-governance-equipping-local-governments-realising-climate

Bradley S, Mahmoud IH, Arlati A (2022) Integrated collaborative governance approaches towards urban transformation: experiences from the CLEVER cities project. Sustainability 14(23):15566. https://doi.org/10.3390/SU142315566

Breuer A, Malerba D, Balasubramanian P, Srigiri S (2022) Governing the interlinkages between the SDGs. Routledge. https://doi.org/10.4324/9781003254683

Bulkeley H (2020) Nature-based solutions towards sustainable communities: analysis of EU-funded projects. Publications Office of the European Union. https://data.europa.eu/doi/10.2777/877034

Dick J, Carruthers-Jones J, Carver S, Dobel AJ, Miller JD (2020) How are nature-based solutions contributing to priority societal challenges surrounding human well-being in the United Kingdom: a systematic map. Environ Evid 9(1):1–21. https://doi.org/10.1186/s13750-020-00208-6

European Commission (2020) Nature-based solutions: state of the art in EU-funded projects. In: Wild T, Freitas T, Vandewoestijne S (eds). https://doi.org/10.2777/236007

Galle NJ, Nitoslawski SA, Pilla F (2019) The internet of nature: how taking nature online can shape urban ecosystems. Anthropocene Rev 6(3):279–287. https://doi.org/10.1177/2053019619877103

Grilli G, Tomasi S, Bisello A (2018) Assessing preferences for attributes of city information points: results from a choice experiment. Green Energy Technol (9783319757735):197–209. https://doi.org/10.1007/978-3-319-75774-2_14

Gudowsky N, Peissl W (2016) Human centred science and technology—transdisciplinary foresight and co-creation as tools for active needs-based innovation governance. Eur J Futures Res 4(1). https://doi.org/10.1007/s40309-016-0090-4

Li Z, Liu Y, Hossain O, Paul R, Yao S, Wu S, Ristaino JB, Zhu Y, Wei Q (2021) Real-time monitoring of plant stresses via chemiresistive profiling of leaf volatiles by a wearable sensor. Matter 4(7): 2553–2570. https://doi.org/10.1016/j.matt.2021.06.009

Li J, Nassauer JI (2021) Technology in support of nature-based solutions requires understanding everyday experiences. Ecol Soc 26(4). https://doi.org/10.5751/ES-12838-260435

Maes J, Jacobs S (2017) Nature-based solutions for Europe's sustainable development. Conserv Lett 10(1):121–124. https://doi.org/10.1111/conl.12216

Mahmoud I, Morello E (2018) Co-creation pathway as a catalyst for implementing nature-based solution in urban regeneration strategies learning from CLEVER cities framework and Milano as test-bed. Urbanistica Informazioni 278(Special issue):204–210. https://re.public.polimi.it/retrieve/handle/11311/1079106/348151/2018_Mahmoud-Morello_XIINU_sessionen3.pdf

Mahmoud I, Morello E (2021) Co-creation pathway for urban nature-based solutions: testing a shared-governance approach in three cities and nine action labs. In: Bisello A et al (ed) Smart and sustainable planning for cities and regions. Springer International Publishing, pp 259–276. https://doi.org/10.1007/978-3-030-57764-3

Mahmoud IH, Morello E (2023) Four years of Co-creation with stakeholders: what did we learn about its added value in Urban Planning? Insights from CLEVER Cities Milan three Urban Living Labs. In: Cerreta M, Russo M (a cura di) La valutazione come parte del processo pianificatorio e progettuale, Atti della XXIV Conferenza Nazionale SIU Dare valore ai valori in urbanistica, Brescia, 23–24 giugno 2022, vol 09. Planum Publisher e Società Italiana degli Urbanisti, Roma-Milano. ISBN 978-88-99237-51-6. http://media.planum.bedita.net/00/7a/Atti%20XXIV%20Conferenza%20Nazionale%20SIU_Brescia_VOL.09_Planum%20Publisher_2023_.pdf

Mahmoud IH, Morello E, Rizzi D, Wilk B (2022) Localizing sustainable development goals (SDGs) through co-creation of nature-based solutions (NBS). In: Bears R (ed) The Palgrave encyclopedia of urban and regional futures. Springer International Publishing, pp 1–17. https://doi.org/10.1007/978-3-030-51812-7_354-1

Mahmoud I, Morello E, Vona C, Benciolini M, Sejdullahu I, Trentin M, Pascual KH (2021) Setting the social monitoring framework for nature-based solutions impact: methodological approach and pre-greening measurements in the case study from CLEVER cities Milan. Sustainability. https://doi.org/10.3390/su13179672

O'Hogain S, McCarton L (2018) A technology portfolio of nature based solutions: innovations in water management. In: A technology portfolio of nature based solutions: innovations in water management, pp 1–122. https://doi.org/10.1007/978-3-319-73281-7

Pirotti F, Piragnolo M, D'Agostini M, Cavalli R (2022) Information technologies for real-time mapping of human well-being indicators in an urban historical garden. Future Internet 14(10):280. https://doi.org/10.3390/fi14100280

Rakha T, El Masri Y, Chen K, De Wilde P (2021) 3D drone-based time-lapse thermography: a case study of roof vulnerability characterization using photogrammetry and performance simulation implications. https://doi.org/10.26868/25222708.2021.30828

Ramzan R, Omar M, Siddiqui OF, Ksiksi TS, Bastaki N (2021) Internet of trees (IoTr) implemented by highly dispersive electromagnetic sensors. IEEE Sens J 21(1):642–650. https://doi.org/10.1109/JSEN.2020.3014387

Scheuer S, Jache J, Kičić M, Wellmann T, Wolff M, Haase D (2022) A trait-based typification of urban forests as nature-based solutions. Urban For Urban Green 78. https://doi.org/10.1016/j.ufug.2022.127780

Sella E, Meneghetti C, Muffato V, Borella E, Carbone E, Cavalli R, Pazzaglia F (2023) The influence of individual characteristics on perceived restorativeness and benefits associated with exposure to nature in a garden. Front Psychol (14). https://doi.org/10.3389/fpsyg.2023.1130915

Snep RPH, Voeten JGWF, Mol G, van Hattum T (2020) Nature based solutions for urban resilience: a distinction between No-Tech, Low-Tech and High-Tech solutions. Front Environ Sci 8(December). https://doi.org/10.3389/fenvs.2020.599060

Tsekeri E, Lilli A, Katsiokalis M, Gobakis K, Mania A, Kolokotsa D (2022) On the integration of nature-based solutions with digital innovation for health and wellbeing in cities. In: 7th international conference on smart and sustainable technologies (SpliTech), pp 1–6. https://doi.org/10.23919/SpliTech55088.2022.9854269

Wellmann T, Andersson E, Knapp S, Lausch A, Palliwoda J, Priess J, Scheuer S, Haase D (2022) Reinforcing nature-based solutions through tools providing social-ecological-technological integration. Ambio. https://doi.org/10.1007/s13280

Zilio S, Borsari A, Bisello A, Segata A, D'Alonzo V, Croce S (2022) Visionary nature based actions for health, well-being & resilience in cities D3.4: report on multiple benefits expected from visionary solutions dissemination level public. https://varcities.eu/wp-content/uploads/2022/11/D3.4_Reports-on-multiple-benefits-expected-from-Visionary-Solutions.pdf