

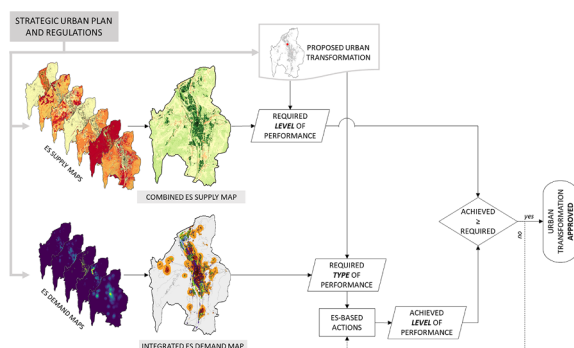
A performance-based planning approach integrating supply and demand of urban ecosystem services

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GRAPHICAL ABSTRACT



ABSTRACT

Performance-based planning is advocated as a promising alternative to more common prescriptive approaches (e.g., traditional zoning), to manage the complexity of current urban development in a flexible and effective way. The aim of this paper is to develop and test an innovative performance-based planning approach built around the assessment of ecosystem service supply and demand. The approach moves from the overall objective of enhancing the provision of relevant ecosystem services in the city. Accordingly, proposed urban transformations are subject to a performance assessment aimed at limiting the negative impact on the current ecosystem service supply and promoting the integration of ecosystem-based actions. The loss in the current supply defines the required level of performance, while the type of performance (i.e. what ecosystem services should be targeted) depends on ecosystem service demand. To support the implementation of the approach, we developed two operational tools: the “combined ES supply” map and the “integrated ES demand” map. A scoring system links the indicators in the two maps and assesses the balance between positive and negative impacts. The proposed approach is tested in the city of Trento, Italy, considering seven urban ecosystem services and three different types of urban transformations. The application reveals strengths and limitations, and offers a proof-of-concept that can be further refined and adapted to other contexts. The study demonstrates how ecosystem service assessments can support the design of technical policy instruments, thus contributing to filling a blindspot on the roles of ecosystem service knowledge in decision-making processes.

1. Introduction

The term “performance-based planning” denotes planning approaches primarily focused on the outcomes of plan implementation, where the emphasis is on the role of the plan as a strategic rather than a

regulatory tool (Baker, Sipe, & Gleeson, 2006). The plan moves from the vision of a desirable future agreed by the community and defines long-term goals and strategies to achieve it. In a purely performance-based system, the plan does not indicate how to pursue the outcomes, but identifies the performance criteria against which actions should be

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assessed (Baker et al., 2006). Hence, the suitability of land uses and activities is not defined ex-ante, but evaluated in each case depending on the expected impacts of the proposed intervention (Frew, Baker, & Donehue, 2016). The lack of predefined rules allows flexibility and promotes dialogue and negotiation between administrations and private developers, which is expected to increase the effectiveness of the planning process, although at the risk of increasing uncertainty and transaction costs.

Performance-based planning is commonly contrasted with prescriptive planning systems focused on defining land uses and regulations to which interventions should comply (Frew et al., 2016; Rivolin, 2008). Zoning is the most common prescriptive model in urban planning. A zoning plan assigns development rights and defines the rules that govern the transformation in each zone of the city. From a public administration perspective, a zoning system presents clear advantages: predictability of the outcomes (hence, reduced uncertainty during the authorization process), ease in the management (hence, lower costs), and consistency across interventions (hence, fairness), among others. However, lack of flexibility and inability to adapt to changing social-ecological and economic conditions are strong limitations of prescriptive planning systems, leading to increasing critiques in the last decades. Instead of reflecting societal expectations, strict planning regulations have often become an obstacle to urban transformation and regeneration, revealing the inadequacy of prescriptive planning systems in directing and managing today's urban development.

So far, however, performance-based planning approaches have found limited application around the world. In Europe, despite a certain interest on introducing the concept of performance in planning (Faludi, 2000), the discussion has mostly focused on large-scale strategic plans and their assessment, with little application, if any, at the urban scale (Rivolin, 2008). Quite the contrary, in the U.S.A., pioneering municipalities experimented performance-based approaches on a voluntary basis already in the early '70s (Baker et al., 2006). However, the main testbeds for performance-based planning have been New Zealand and Queensland, Australia, where it was adopted through national laws during the '90s. Drawing on a review of real-life applications in these three countries, Baker et al. (2006) note that, despite the broad support from both planners and developers, the implementation of performance-based planning has not been very successful. In most cases, after few years of experimentation, local governments re-introduced some prescriptive elements in the planning system, thus generating a constellation of hybrid approaches. The authors identify the critical aspects that lead to this progressive abandonment of purely performance-based approaches, which can be summarised into two main points: i) the administrative burden associated to setting up and managing the system, and ii) the uncertainty about the outcomes of plan implementation. Key reasons for the latter are the difficulties associated to assessing the expected impacts of interventions, to accounting for the cumulative effects of multiple transformations, and to monitoring the implementation.

Both critical issues, however, appear today less challenging than some decades ago. Planning practices now commonly rely on advanced GIS technologies, a large availability of spatial data, and easy-to-use modelling tools tailored to the specific conditions of urban areas, which allow ex-ante assessment of planning scenarios and follow-up on plan implementation (Lakes & Kim, 2012; Pelorosso, 2019). For example, Langemeyer and colleagues have recently shown how to select location and typology of green roofs in Barcelona to optimise the overall performance against multiple environmental, social, and economic objectives (Langemeyer et al., 2020). Such advancements can potentially help to overcome the practical limitations that emerged in early applications of performance-based planning approaches, and might support a new wave of experimentation (Pelorosso, 2019). In fact, the interest on performance-based planning seems to be growing again, as demonstrated both by the most recent scientific literature (La Rosa & Pappalardo, 2019) and by the increasing number of attempts to

integrate performance-based measures in policies and plans, especially in relation to some of the environmental challenges that characterise urban areas (Pappalardo & La Rosa, 2019).

In fact, the origin of performance-based planning lies in the environmental field, where a flexible approach focused on setting desirable targets – rather than strict regulations on how to achieve them – has been considered appropriate to tackle environmental problems (Baker et al., 2006). For example, targets and related performances about air and water pollution, noise, and other hazards can be set based on safety thresholds or carrying capacity, leaving to the developers to select the best way to achieve them, within the available range of (continuously improving) technological solutions. This allows performance-based approaches to accommodate the continuous innovation in the way environmental issues are addressed, both at the conceptual (framing) and at the practical level (solutions), while maintaining stable and well-defined overall objectives. In 1997, the Integrated Planning Act that introduced performance-based planning in Queensland (Australia) made explicit reference to the concept of ecological sustainability as one of its founding principles (Frew et al., 2016). Recently, performance-based planning has been proposed as a suitable way to promote and integrate Nature-Based Solutions, since it is flexible enough to embrace multi-functionality and urban complexity (Dorst, van der Jagt, Raven, & Runhaar, 2019).

Today, while we acknowledge that environmental issues, especially in urban areas, are intertwined with socio-economic aspects, we expect urban planning to manage the complexity of urban transformations so that they enhance the quality of life in the city in a wide sense. From this perspective, the concept of ecosystem services (ES) can be a considered a suitable framework to describe the relation between the environmental aspects involved in urban interventions and their consequences on human wellbeing (Cortinovis & Geneletti, 2019). In the last years, a wide scientific literature has proposed and refined methods for ES mapping and assessment that can be applied to predict the expected impact of proposed interventions on ES supply, as well as the demand for ES that arises from current or foreseen socio-economic conditions (Grêt-Regamey, Sirén, Brunner, & Weibel, 2017; Haase et al., 2014). Integrating ES knowledge has been promoted by many as a way to increase the quality of planning decisions (Geneletti, Cortinovis, Zardo, & Esmail, 2020; Guerry et al., 2015; TEEB, 2010). Studies investigating the integration through the analysis of planning documents (Cortinovis & Geneletti, 2018; Hansen et al., 2015; Kabisch, 2015) and stakeholders' opinions (Albert, Aronson, Fürst, & Opdam, 2014; Beery et al., 2016) have revealed potentials and opportunities, but also complexities, uncertainties, and barriers (Kaczorowska, Kain, Kronenberg, & Haase, 2015; Saarikoski et al., 2018). However, case studies demonstrated how mainstreaming ES knowledge through a successful science-policy interface can direct planning decisions towards more sustainable development trajectories (Ruckelshaus et al., 2015). An expectation that has recently led the European Commission to publish a guidance on how to integrate ES in a wide range of decision-making processes, not least urban planning (European Commission, 2019).

The aim of this paper is to develop a performance-based planning approach, based on the information produced by ES mapping and assessment at the urban scale. More specifically, we propose an approach that, based on the assessment of ES supply and demand, estimates the impacts of the urban transformations envisioned by the plan, and defines for them appropriate and proportionate requirements. We describe the rationale behind the approach and the results of its testing in a case study, the city of Trento in northern Italy, where we discussed it with local stakeholders involved in drafting the new urban plan. In doing so, we offer a proof-of-concept that can be further refined and adjusted to suit the specificities of different contexts.

By linking the two fields of performance-based planning and ES mapping and assessment, we demonstrate how the integration of ES can become a driver of innovation in current planning practices (Ahern,

Cilliers, & Niemelä, 2014), not just by suggesting a new conceptual framing or potential ecosystem-based actions, but by shaping the on-the-ground mechanisms through which urban transformations are assessed and approved. The study shows the use of ES assessments to support the design of a technical policy instrument: a potential role that emerges as a blindspot in the literature on both economic valuation (Laurans, Rankovic, Billé, Pirard, & Mermet, 2013) and biophysical assessment of ES (Lautenbach et al., 2019). In previous real-life spatial planning applications, an “instrumental use” of ES knowledge has been identified in the analysis of trade-offs and in the impact assessment of planning actions during the drafting of the plan (Mckenzie et al., 2014). Here, we make a step further and test the use of ES knowledge as an operational support to the implementation stage through the design of a technical instrument, thus contributing to expanding the scope of ES integration in planning processes.

2. Overall approach to integrate ecosystem services in performance-based planning

2.1. Rationale

A common underlying rationale of performance-based planning approaches is that urban transformations must meet certain levels of performance to be considered acceptable, hence approved. *Performances* correspond to the capacity of urban transformations to positively contribute to the objectives of the plan, and their assessment is carried out with respect to targets (“requirements” or “required performances”) that descend from the plan’s objectives. The process of approval of urban transformations is therefore a process of impact assessment: a transformation is approved if, overall, it contributes to achieving the plan’s objectives. The definition of requirements allows measuring impacts against both quantitative and qualitative objectives.

To integrate ES assessments in a performance-based planning system, we move from the consideration that urban transformations may have both positive and negative impacts on the provision of urban ES. Here, we use the term “urban transformations” to broadly refer to all physical interventions envisioned or allowed by a plan, not limited to land use changes (e.g., urban densification is included in the definition). On the one hand, urban transformations that increase soil sealing, diminish canopy coverage, or fragment valuable habitats may reduce the current supply of ES, thus negatively affecting citizens’ wellbeing (Alberti, 2005). On the other hand, urban transformations that integrate ecosystem-based actions and nature-based solutions may provide multiple benefits to the surroundings, especially in strongly urbanised areas. For example, they may contribute to water-flow regulation, thus preventing urban floods (Haghighatafshar et al., 2019), or to mitigate heat waves by creating cool islands (Zardo, Geneletti, Pérez-Soba, & Van Eupen, 2017), thus reducing health risks associated to high temperatures (Venter, Krog, & Barton, 2020). In general, the same transformation produces at the same time both positive and negative impacts, usually on different ES (Haase, Schwarz, Strohbach, Kroll, & Seppelt, 2012). Hence, two broad ES-related objectives that urban transformations should pursue are: i) minimizing the negative impacts on the current ES supply, and ii) maximizing the positive impacts on the provision of ES highly demanded in the area of intervention.

Our approach combines these two objectives to ensure that the inclusion of ecosystem-based actions offsets the negative impacts generated by the urban transformation. Since enhancing citizens’ wellbeing should be the overall objective of the plan, the assessment takes into account of the spatial variability of ES demand across the city and of the different importance of ES benefits in different areas. Positive and negative impacts are not compared separately for each ES, but rather they are balanced in an overall assessment of the urban transformation, based on the principle of out-of-kind compensation. A reduction in the current supply of one ES can be compensated by an increase in the provision of other ES, provided that the latter are chosen among the

most needed in the specific location where the intervention takes place. The assessment is therefore based on the analysis of both the supply and the demand of selected ES, identified as relevant to the context. The analysis of existing supply sets the basis for assessing the negative impacts of the urban transformation, while the analysis of demand is necessary to measure the positive impacts from a citizens’ wellbeing perspective.

Within this conceptual framework, defining the performances and related requirements for urban transformations involves addressing two aspects: i) what level of performance is required, i.e. how much ES supply should be provided by the urban transformation; and ii) what type of performance is required, i.e. what ES should be prioritised. In the proposed approach, the level of performance depends on the expected impact on the current ES supply: the greater the reduction in the current supply, the higher the performance that is required. The type of performance depends on the demand, i.e. on the level of priority that different ES assume in different areas of the city.

2.2. Operationalization

From an operational perspective, the implementation of the proposed approach in a planning process requires tools that allow a rapid assessment of the expected impacts of the urban transformation, hence the definition of performances and requirements. In the case study application, two maps were prepared to support the implementation of the proposed performance-based planning approach: a “combined ES supply” map and an “integrated ES demand” map.

The “combined ES supply” map summarizes information on the supply of multiple ES and it is used to compute an overall quantitative indicator that summarizes the expected negative impacts of the urban transformation. The indicator depends on the location of the urban transformation and corresponds to the overall supply of ES in the area of intervention. The quantitative values in the “combined ES supply map” are divided into classes. Each class is assigned a score that represents the level of performance required to the urban transformation.

The “integrated ES demand” map summarizes information on the demand for multiple ES across different areas of the city. It is generated by clustering individual demand maps in order to identify areas in the city characterised by the same “demand profiles”, i.e. priorities in terms of ES demand. The clusters identified in the “integrated ES demand map” are associated to the type of performance required to the urban transformation. Depending on the location, ecosystem-based actions gain a different score based on the level of priority of the targeted ES in that cluster of demand: the higher the demand for the ES that is enhanced, the higher the score. In this way, the approach prioritizes the most demanded ES in each area of the city.

Through the implementation of ecosystem-based actions, each urban transformation must gain a score at least equal to the score corresponding to the required level of performance. Thus, the score serves as a link between positive and negative impacts, i.e. between supply and demand of multiple ES, and translates the conceptual approach of balancing the impacts in an operative way.

In a real-life application, ecosystem-based actions should be selected from a list compiled by the municipality, which details the minimum requirements to earn the corresponding scores. For example, the actions targeting run-off mitigation may include covering all new buildings with green roofs and maintaining a minimum share of permeable surfaces in the area of intervention. The score gained by implementing these actions will depend on the level of demand for run-off mitigation where they are implemented. As shown by the example of permeable surfaces, possible ecosystem-based actions also include the conservation of existing ecosystems and related ES. The fact that existing ES supply is not necessarily lost (or anyway not entirely) when urban transformations are implemented is taken into account when assessing the level of performance achieved by each urban transformation: whatever is preserved contributes to the positive impacts. In this

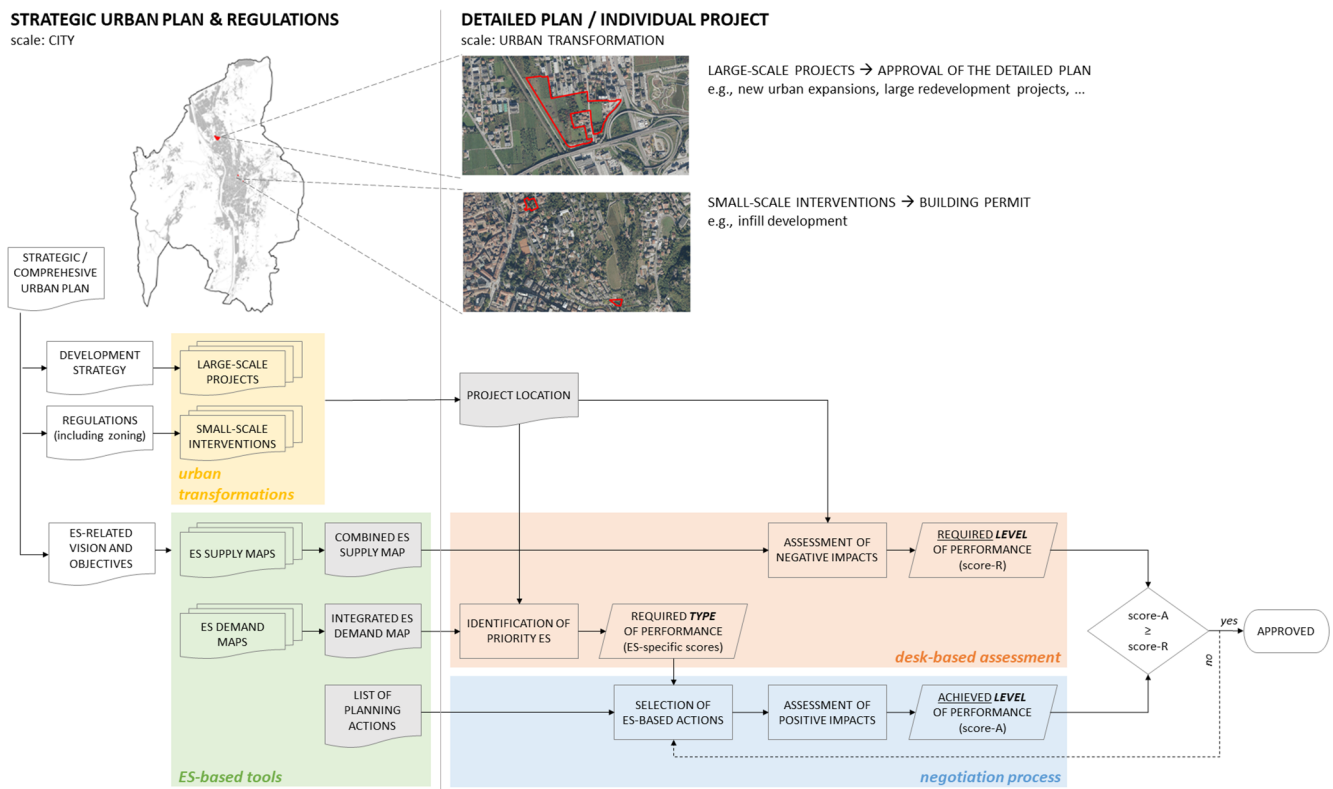


Fig. 1. Workflow of the proposed performance-based planning approach integrating the assessment of ES supply and demand. The terms “strategic/comprehensive plan” and “detailed plan” are used in a broad sense to indicate the different decision-making levels involved, hence their meaning might be inconsistent with country-specific terminologies.

respect, our approach differs from existing decision-support systems that consider only the potential negative impacts of urban transformations on ES provision, e.g. the PALM tool (Grêt-Regamey, Altwegg, Sirén, van Strien, & Weibel, 2017).

Fig. 1 provides an overview of the main stages of the proposed approach and indicates the role of the ES-based tools in the case study application.

3. Materials and methods for the case study application

3.1. Case study and selection of relevant ecosystem services

The case study selected to test the proposed approach is Trento, an alpine middle-sized city of around 120,000 inhabitants in north-eastern Italy. The city lays in a valley floor at an elevation of around 200 m a.s.l., surrounded by alpine peaks. The urban development has been influenced by the presence of the river Adige and by the topography of the site. The main settlement has an elongated shape that follows the course of the river and hosts around 70% of the population, while the rest spreads across the hillsides in small villages, still part of the administrative area of the city.

The narrow valley floor is strongly urbanised, with soil sealing being one of the main issues, challenging stormwater management and producing an intense urban heat island effect. The proximity of residential areas to the main transport infrastructure that run along the valley makes air quality and noise two other critical environmental aspects. At the same time, the location of the city determines a general high proximity of urban areas to natural environments. More than 10 km² of the city administrative area is designated as natural protected area, including eight Natura 2000 sites and four local reserves, while around 1/3 is covered by forests. These are also valuable places for nature-based recreation, while urban green areas are lacking in some neighbourhoods, especially in the densest part of the city. Given its large

administrative area, the city is the top agricultural producing municipality in the province, with vineyards and apple orchards that occupy some patches in the valley floor and in the sunniest hillsides. So far, the high value of the agricultural productions has secured the conservation of these non-urbanised patches, but urbanisation pressure is strong, especially close to existing settlements.

The drafting of the new Urban Plan for Trento, initiated in 2017 and concluded in 2019, provided the opportunity to reflect on how ES knowledge could be integrated in the planning process. To this aim, we worked in close collaboration with key staff from the city administration on different actions, among which is the development of the performance-based approach described in this paper. The civil servants involved discussed the selection of relevant ES to include in the analysis and provided feedback on the proposed approach.

The selection of ES was based on the strategic document approved by the municipal administration of Trento at the beginning of the planning process, which defined the main goals and strategies that should steer the drafting of the new urban plan (Comune di Trento, 2018). From the content analysis of the strategic document and the discussion with the municipal staff, we identified seven urban ES considered relevant for the ongoing planning process, namely microclimate regulation (cooling), habitat provision, (nature-based) recreation, noise mitigation, air purification, runoff mitigation, and food provision. We assessed the current supply of all the seven ES to determine the expected negative impacts of the urban transformations, hence the level of performance to require. The assessment of demand and the definition of the type of performance, instead, was limited to five out of the seven ES mentioned in the strategic document. We excluded air purification, because ecosystem-based actions that can be implemented in the urban transformations envisioned by the plan (e.g., tree planting in new residential areas) are not expected to significantly contribute to its enhancement, and habitat provision, considering that the available data were not sufficiently detailed to capture the potential effects of small-scale interventions.

Table 1

Methods and indicators to assess the supply of the selected urban ES in Trento. More details on methods and data can be found in the [Supplementary Material](#).

Urban ES	Supply indicator	Method
Microclimate regulation (cooling)	Cooling capacity of green infrastructure	Spatial modelling based on Zardo et al. (2017)
Habitat provision	Relative richness of focal species	Ecological modelling (see Pedrini, Tattoni, and Brambilla (2013) for further details)
Recreation	Recreation Opportunity Spectrum	Spatial modelling through ESTIMAP-recreation including input from local experts (see Cortinovis et al. (2018) for further details)
Noise mitigation	Reduction of traffic noise at selected receivers (residential buildings)	Spatial modelling through OpeNoise QGIS plug-in (Arpa Piemonte, 2019)
Air purification	PM10 deposition	Proxy based on vegetation typology and distance from main sources
Runoff mitigation	Runoff avoided due to infiltration	Proxy based on the share of permeable areas
Food provision	Land suitability for agriculture	Proxy based on current crop typology and suitability to agricultural use

Table 2

Required levels of performance (score) corresponding to different classes of expected impact on the current ES supply. The classes are defined based on the average value of the indicator in the “combined ES supply” map.

Average value of the indicator	Expected impact on ES supply	Required score (level of performance)
$0.0 \leq x < 0.2$	Low	2 point
$0.2 \leq x < 0.4$	Medium	4 points
$0.4 \leq x < 0.6$	High	6 points
$0.6 \leq x \leq 1.0$	Very high	8 points

3.2. Building the combined ES supply map and defining levels of performance

The “combined ES supply map” summarizes the supply of the seven ES selected in the case study. The single ES supply maps were produced adopting various methods, ranging from process-based models to the use of proxy ([Table 1](#)). We selected the methods depending on data availability and resource requirements. Whenever available, we preferred methods specifically targeting the urban scale.

The seven maps of ES supply were rescaled to a 0–1 range and then summed. Since the strategic document did not report any information about the relative importance of the seven ES, we considered them to be equally relevant in the case study, hence assigned them the same weight in the calculation. Finally, the combined map was normalized to a 0–1 range, so that 0 corresponds to pixels that currently supply none of the analysed ES, while 1 corresponds to pixels with the maximum combined level of ES supply that can be found within the municipal area.

The average value of the “combined ES supply map” within the area affected by the urban transformation defines the required level of performance. For simplicity, we classified the values into four classes corresponding to four levels of performance ([Table 2](#)). The definition of the classes accounted for the asymmetrical skewed distribution of the values of the indicator both in the original map and in maps simulating the average values potentially associated to transformations of different spatial extent (the latter were produced by applying to the original maps filters of different size).

Table 3

Methods and indicators to assess the demand of the selected ecosystem services in Trento. More details on methods and data can be found in the [Supplementary Material](#).

Urban ES	Intensity of hazard/level of deprivation	Population/physical assets exposed and vulnerability	Benefiting area
Microclimate regulation (cooling)	Class of cooling effect	Total population + vulnerable classes (children and elderlies)	100-m buffer
Recreation	Distance from the closest area offering high-level recreational opportunities	Total population	300-m buffer
Noise mitigation	Noise from roads and railroads above 65 dB	Residential buildings	Buildings potentially shielded by green barriers
Runoff mitigation	Percentage of impermeable surfaces	Total population + areas for commercial, productive, and service use	Urban sub-watershed
Food provision	Distance from the closest community garden	Families without private garden	500-m buffer

3.3. Building the integrated ES demand map and defining types of performance

The “integrated ES demand map” summarizes the demand for the five ES selected to prioritise ecosystem-based actions in different areas of the city. The demand for each ES was defined, in each point, as a combination of two factors: i) the intensity of hazard (in the case of regulating services) or level of deprivation (in the case of provisioning and cultural services) that characterizes the analysed area with respect to the specific ES under consideration, and ii) the amount of population or physical assets exposed to that condition, taking into account of different vulnerability levels, whenever relevant ([Table 3](#)). Then, for each pixel, a service benefitting area was defined as the area that could potentially benefit from the ES supplied by that pixel ([Table 3](#)). This is to account for the fact that, for example, the level of demand for recreation associated to a new park is not given by the number of people living within the area occupied by the park, but by the number of potential users living in the surrounding area (i.e., benefitting area), considering the current availability of other recreational opportunities. This way, the final indicators reflect the positive impact that can be expected from the implementation of ecosystem-based actions that enhance the provision of ES in different areas of the city.

A cluster analysis was conducted on the five maps of ES demand to identify areas characterised by similar profiles of demand across the municipality. To reduce correlation among the input maps due to the use of population data in different assessments, we run a preliminary Principal Component Analysis and selected the first three components based on Joliffé's criterion (eigenvalue > 0.7), which resulted in explained variance > 85%. We then identified the clusters through unsupervised classification of the three maps corresponding to the three PCA components, applying a k-mean cluster algorithm. The optimal number of clusters was defined by combining different criteria:

- i. statistical criteria, i.e. the common “elbow” ([Kabisch & Haase, 2014](#)) and “silhouette” methods ([Schirpke et al., 2019](#)), and the comparison of statistical indexes provided by the *NbClust* R package ([Charrad, Ghazzali, Boiteau, & Niknafs, 2014](#));
- ii. cartographic criteria, i.e. the number and size of the resulting areas; and

Table 4

Scores assigned to ecosystem-based actions based on the level of priority of the targeted ecosystem service. For each ecosystem service in each cluster, the level of priority is defined as the distance between the average values of the demand in the cluster and the global mean (Z score).

Distance of the average value of the cluster from the global mean (Z-score)	Score assigned to actions
$Z < 0$	0 points
$0 \leq Z < 0.7$	1 points
$0.7 \leq Z < 1.4$	2 points
$1.4 \leq Z < 2.1$	3 points
$Z \geq 2.1$	4 points

iii. interpretational criteria (i.e., possibility of identifying meaningful variances in the values of the demand indicators across the different clusters).

The final “integrated ES demand map” classifies the territory in 6 clusters. Small areas corresponding to single pixels (400 m²) were removed by merging them with the neighbouring area that shared the longest part of their perimeter.

For each demand indicator, we compared the average value within each cluster with the global average. The resulting Z-score was then classified into 5 classes. The classes correspond to the scores urban transformations gain when implementing actions that enhance the provision of the respective ES in that specific cluster (Table 4).

For each of the selected ES, an illustrative list of possible actions was compiled based on a previous review of ecosystem-based actions included in urban plans (Cortinovis & Geneletti, 2018).

All spatial analyses were conducted in a raster environment with a resolution of 20 m using the open-source software Q-GIS 3.4 and GRASS 7.6. R was used for the PCA and k-mean cluster analyses (packages *factoextra*, *cluster*, and *NBClust*). The Supplementary Material provides a detailed description of the methods for mapping ES supply and demand, and of the data used for the analyses.

3.4. Testing the approach on selected urban transformations

We tested the approach in the case study on a set of urban transformations. The main objective of the test was to demonstrate the applicability of the proposed mechanism to potential transformations of different sizes, characterised by different current and future land uses, and located in different areas of the city. We also aimed to verify the overall feasibility of the requirements and the coherence between the required levels of performance and the scores gained by implementing ecosystem-based actions in the different clusters. To this purpose, we selected four urban transformations included in the urban plan of the city under revision. The four transformations were not implemented during the period of validity of the plan, but the new plan was expected to confirm them. The selected urban transformations include two small residential lots for in-fill development within the most urbanised area of the city, a large mostly residential expansion in the peri-urban area, and a new productive site outside the urban settlement.

4. Results

4.1. The combined ES supply map and the levels of performance

The maps of the current supply of the seven ES (Fig. 2) are characterised by different spatial distributions, with some similarities that suggest the presence of synergies and bundles resulting from the multifunctionality of some green infrastructure components (Cortinovis & Geneletti, 2019; Hansen & Pauleit, 2014). The map of microclimate regulation (Fig. 2a) is the most dissimilar, since the ES was analysed only in the valley floor. The map of habitat provisions (Fig. 2b) reveals

the presence of some biodiversity hotspots both in the forested slopes to the east and the west of the city, and in the valley floor. High-level opportunities for recreation are spread across the whole municipal area (Fig. 2c): some hotspots, corresponding to the largest urban parks, emerge in the main settlements, but most of the areas with the highest value of the indicator are forests and mountain areas used for a variety of outdoor recreational activities (Cortinovis, Zulian, & Geneletti, 2018). Forests also play a crucial role in air purification, but the concentration of pollutants is a key factor affecting the supply, hence areas close to the main roads emerge as the most important for the supply of the service (Fig. 2e). Similar distribution, due to the same importance of the spatial relation with the sources of disturbance, is shown in the map of noise mitigation (Fig. 2d). However, only vegetation acting as a barrier between traffic noise and residential areas is identified as a service providing unit here, hence forests where roads and railroads run far from human settlements do not generate any ES. The map of runoff mitigation (Fig. 2f) clearly reflects the intensity of soil sealing, especially relevant in the historical centre and in the productive and commercial areas to the north. Finally, the map of food production (Fig. 2g) shows the presence of high-valuable agricultural areas in the whole valley floor and on the sunny hillsides to the east.

The “combined ES supply” map (Fig. 3) summarizes the results of the seven assessments of ES supply. Urbanised areas with little or no vegetation are clearly visible in the map as characterised by the lowest values of the indicator. The highest values, on the contrary, are mostly found in peri-urban patches, relatively close to the settlements. Some of them corresponds to main urban parks and protected areas, but the majority are remnants of vegetation, especially forests, now enclosed between urbanised areas. The distribution of the values depends on the selection of ES that mostly targeted the “urban” ones, with focus on the demand by the citizens. Hence the large part of the territory covered by forests, which play a key role in the provision of a wide range of ES not considered in this analysis, receives on average a low score.

4.2. The integrated ES demand map and the types of performance

The demand for ES is affected by the distribution of people across the city (Fig. 4), hence the related maps are more similar compared to those of the current supply. The valley floor is characterised by the highest concentration of ES demand in all the five maps, although the hotspots vary depending on the ES. In the case of cooling (Fig. 4a), the city centre and the surrounding areas emerge as the most in need of this ES due a combination of high population density and low presence of green infrastructure. The demand for recreation (Fig. 4b) is more dispersed and, despite showing a hotspot in the city centre, it reveals the presence of residential areas with low availability of recreational opportunities also in more peripheral zones. The demand for noise mitigation (Fig. 4c) is clearly determined by the presence of transport infrastructures, especially the highway and railroads that run along the valley floor very close to residential areas. The demand for runoff mitigation (Fig. 4d) is affected by the current level of soil sealing and peaks in the industrial and commercial areas to the north, where the lack of permeable surfaces combines with a higher vulnerability to urban flooding. Finally, the demand for food production from urban gardens (Fig. 4e) reflects the presence of multi-family houses far from existing community gardens. It is especially high in the residential areas north of the city centre and in some peripheral neighbourhoods on the western hillsides, while the southern and eastern neighbourhoods are characterised by a higher share of single-family houses and villas and by the presence of municipal areas recently converted into community gardens.

The “integrated ES demand” map (Fig. 5) summarizes the five assessments of ES demand and classifies areas across the municipality characterised by similar profiles. Through the principal component analysis and cluster analysis, we identified six profiles that can be used to describe different ES priorities in Trento, hence to direct the selection

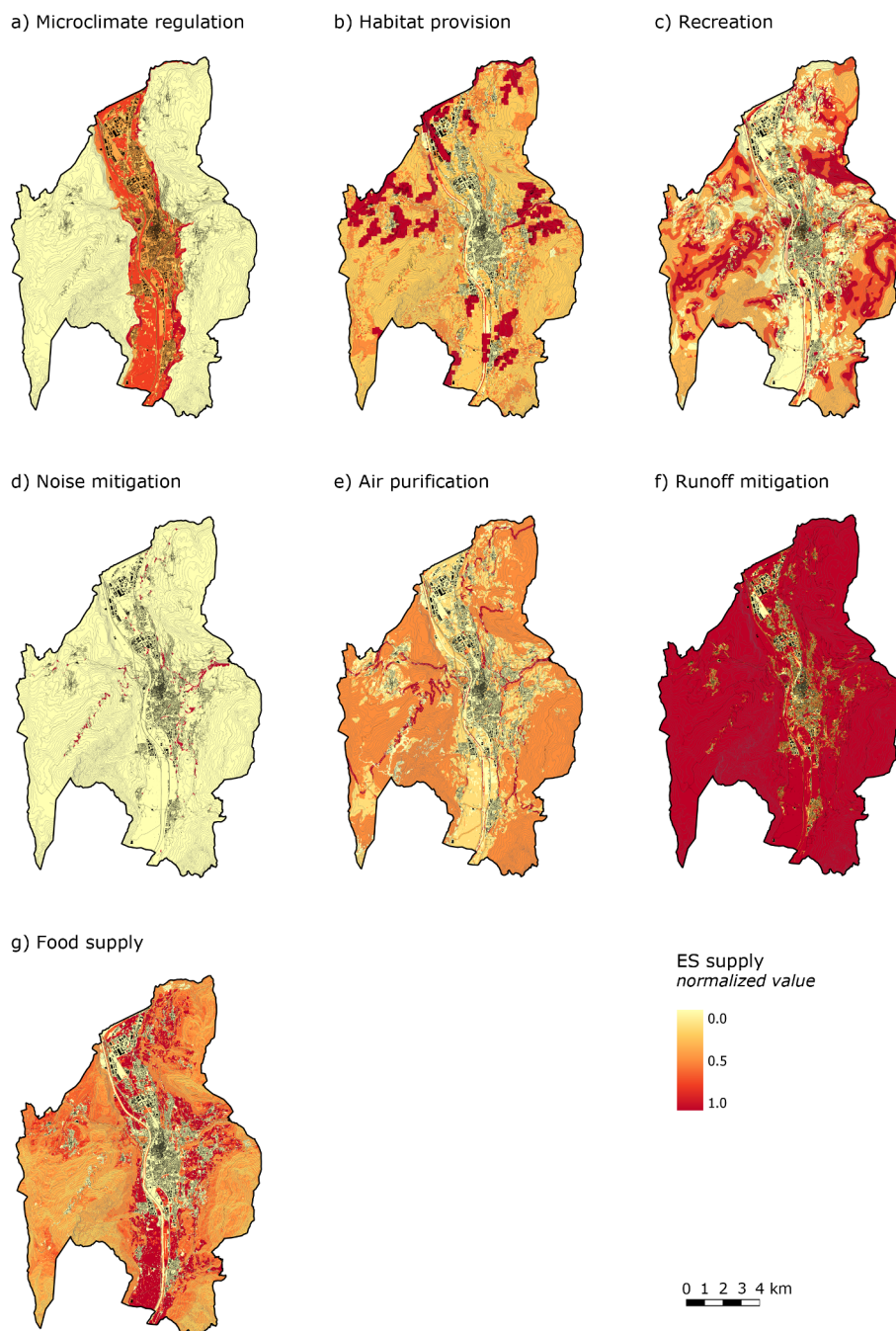


Fig. 2. Maps of the current supply of the seven selected ES in Trento: normalized value of the indicators in Table 1.

of ecosystem-based actions. The spider diagrams (Fig. 6) that accompany the map describe the level of demand for the analysed ES in each cluster. The clusters have variable spatial extent, ranging from around 1.5 km² of cluster 1 to almost 116 km² of cluster 3.

Cluster 1 is composed by areas with high demand for runoff mitigation, including industrial districts in the northern part of the city and other high-density residential neighbourhoods in the southern part characterised by a high degree of soil sealing. The demand for the other ES is low, with only microclimate regulation and recreation slightly above the global mean. Cluster 2 is composed by areas with relatively high demand for runoff mitigation, although on average lower than in Cluster 1, and higher-than-average demand for microclimate regulation, food supply, and recreation. It mainly comprises peripheral neighbourhoods both in the valley floor and on the hills, with a mixture of industrial and residential uses. Cluster 3 is characterised by very low or no demand for the five analysed ES, and

includes all non-urbanised areas far from any settlement, hence from potential ES beneficiaries. Cluster 4 is composed by peri-urban areas surrounding the main settlements, mostly non-urbanised areas or low-density residential neighbourhoods. These are characterised by a higher-than-average demand for microclimate regulation, recreation, and food supply, with a prevalence for the latter. Cluster 5 comprises the main residential areas with a medium to high density, including the historic centre and other historical settlements to the west and to the south. These areas are characterised by the highest demand for microclimate regulation, recreation, and food production across the municipality and by a higher-than-average demand for runoff regulation. Finally, specific of Cluster 6 is the demand for noise regulation. Areas in Cluster 6 are enclosed between transport infrastructures and medium-to-high density residential blocks, hence in general are also characterised by a higher-than-average demand for all the other ES.

Ecosystem-based actions aimed at strengthening ES provision

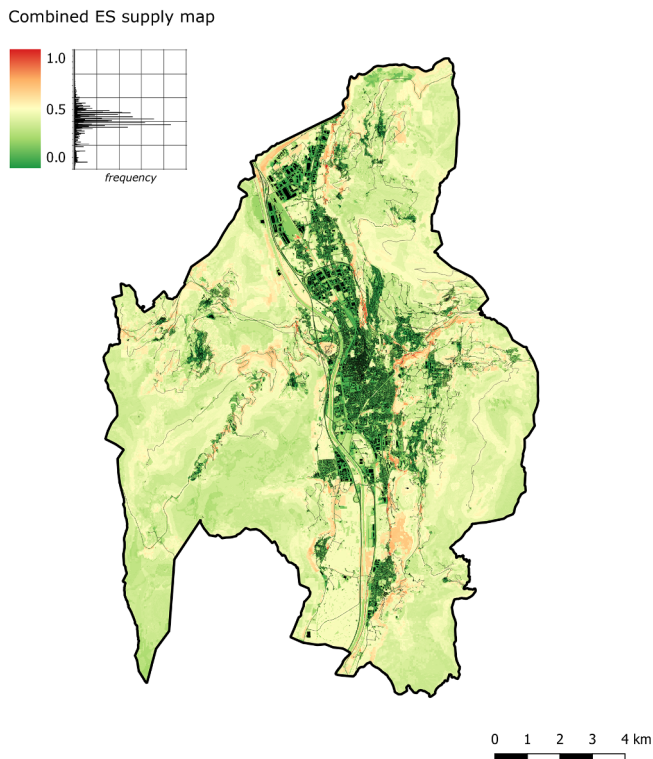


Fig. 3. The “combined ES supply map” for Trento.

receive a different score depending on the demand profile of the cluster in which they are implemented, as shown in Table 5. Scores range from zero to four. Zero corresponds to areas where the ES is not demanded at all or where the demand is very low, hence actions targeting the ES are discouraged. Four corresponds to areas where the demand for the ES is the highest and actions to improve its provision should be considered a priority. Each of the five ES is prioritised in at least one cluster and in each cluster except for Cluster 3 it is possible to score at least 2 points by targeting the prioritised ES. The case of urban transformations implemented in Cluster 3, where the demand for all ES is low or very low, requires the consideration of off-site compensation measures, as exemplified in one of the testing applications.

4.3. Requirements identified for selected urban transformations

To test the proposed approach and the scoring system, we selected four urban transformations and applied the workflow in Fig. 1 to define the level of performance and the priority ES in each case. Fig. 7 shows the current state of the areas where the urban transformations are located and the respective sub-windows of the “combined ES supply” and the “integrated ES demand” maps.

For the first test, we selected two vacant lots within the most urbanised part of the city, identified by the plan as areas for in-fill development (Sites A and B in Fig. 7). The two sites are located in the same neighbourhood. Site A has an area of around 2400 m² and is currently a private garden with sparse trees, completely surrounded by developed land. Site B is a sloped terrain of approximately 1000 m² at the border of the built-up area and is covered by trees. The average values of the “combined ES supply” map differ between the two sites, being 0.23 for A and 0.54 for B. Accordingly, the expected impact on the current ES supply produced by the urban transformation in Site A is “medium”, while the one in lot B is “high” (Table 2). The former corresponds to a required score of 4, while the latter corresponds to 6. Since both lots fall in the same cluster of the “integrated ES demand” map, the priority ES to target through ecosystem-based actions are the same. The highest priority in the cluster is assigned to microclimate

regulation, food supply (urban gardens), and recreation. Actions targeting these three ES receive 4 points. A lower priority is given to runoff mitigation; therefore, actions targeting this ES receive 2 points.

To achieve the required level of performance, urban transformation in Site A must implement at least one action aimed at strengthening one of the three priority ES in the cluster. Given the small size of the intervention, it would be difficult to implement on-site actions that enhance recreation and food production. However, it is possible to maintain and increment the current tree coverage, at least in part of the area. This would guarantee a good performance of the area from the point of view of microclimate regulation, benefitting both the future inhabitants and the surrounding residents. For the urban transformation in Site B, implementing actions to enhance microclimate regulation would not be sufficient to achieve the required level of performance (i.e., 6 points). In this case, the intervention could also include an action targeting runoff regulation. Despite not being an absolute priority in the area, ecosystem-based actions aimed at enhancing the provision of this ES would contribute to maintain the current good condition even after the increase in the demand due to the urban transformation, thus preventing critical situations to emerge in the future.

The second test (Site C, Fig. 7) concerns a large urban expansion of around 5.5 ha at the border of the currently urbanised land, surrounded by transport infrastructures: a large junction between two main roads to the south and the east, and a railway to the west. At present, the area is mainly devoted to arable land and orchards, with some patches of grasslands and forests. The eastern part also includes a parking area for trucks and agricultural machineries. The plan envisages here a new residential neighbourhood. The “combined ES supply” map shows different values across the area, with highest impacts corresponding to the remaining woodlands and the lowest in the eastern part. The average value of the indicator is 0.41, corresponding to an overall “high” expected impact on the current ES supply and a required score of 6 points (Table 2). As in the previous case of Site B, the new intervention must therefore include at least two ecosystem-based actions to reach the required level of performance.

Given its size, Site C falls in different clusters in the “integrated ES demand” map. Mostly, they are Cluster 6, where the priority demand is that for shielding the noise produced by existing roads and railways, and Cluster 5, where the demand is driven by the presence of the surrounding residential neighbourhoods (Table 5). Smaller portions fall in Cluster 2 and 4. Therefore, in this case, the “integrated ES demand” map supports not only the selection of ecosystem-based actions, but also their preferred location in the area. Considering the dimension of the intervention, an option could be to realize a public space, such as a park or a community garden. If localized within the portion of the area in Cluster 5, i.e. close to the surrounding residential neighbourhood, the latter would gain a score of 4 points, while they would gain 3 points if localized in Cluster 6, i.e. in a relatively less-accessible area for the surrounding residents. Then, to reach the total required score, it could be possible to realize a green noise barrier within the portions of the area classified in Cluster 6.

The last urban transformation considered in the testing is a new industrial site outside the existing urban areas (Site D, Fig. 7). The area covers around 5 ha in the south-western part of the municipality, currently almost equally divided between apple orchards to the south-east, a fallow field to the south-west, and an abandoned area with some buildings and a large parking lot for campers, without vegetation but mostly unsealed, to the north. On the “combined ES supply” map, the three main land uses correspond to different levels of expected impacts. The average value of the indicator is 0.49, hence the transformation is classified as of “high” expected impact, with associated required score of 6 points (Table 2). However, as shown in Fig. 7, the specificity of this case lays in the fact that, due to its distance to existing urban areas, the demand for all the analysed ES in this area is lower than average (Cluster 3), hence there is no ES to prioritise and no on-site action that allows gaining the required score.

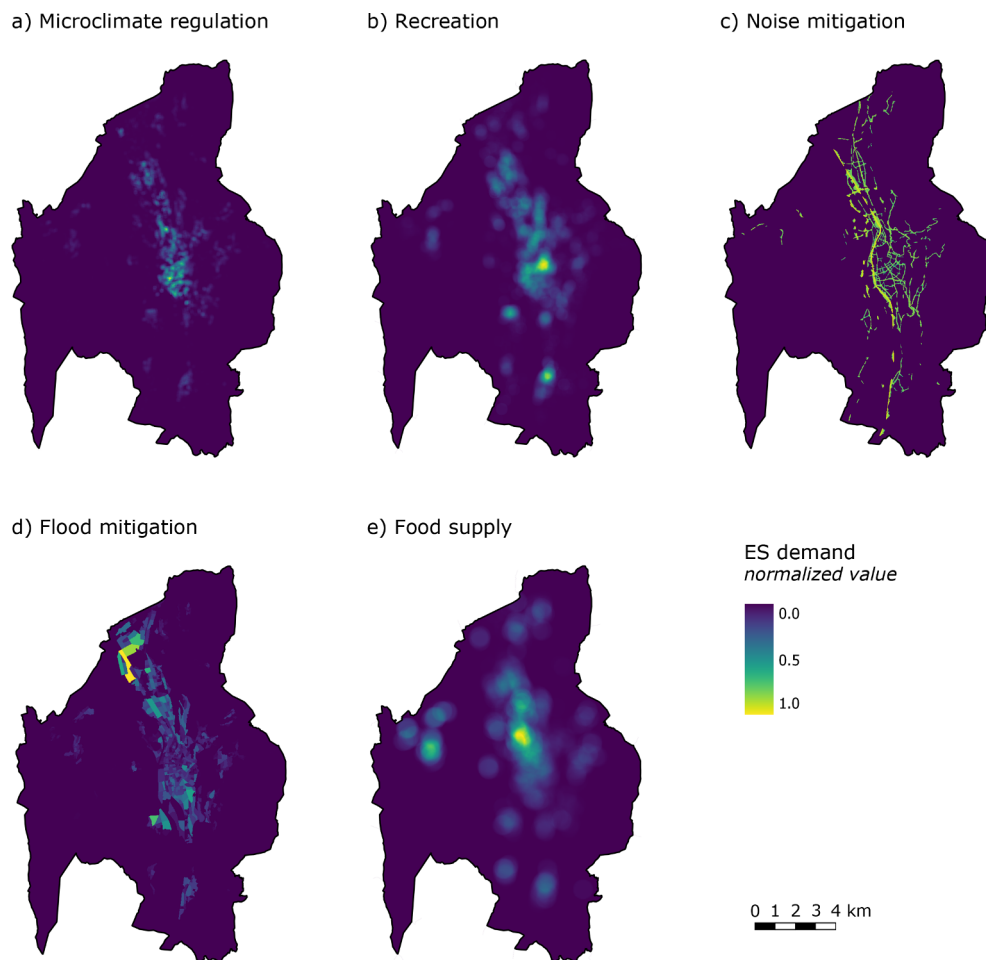


Fig. 4. Maps of the demand for the five ecosystem services potentially targeted by ecosystem-based actions in Trento: normalized value of the indicators listed in Table 2.

In this case, as in all other cases in which it is not possible to realize on-site ecosystem-based actions, the proposed performance-based approach may include the option of off-site compensation. If the municipal administration opens to this possibility, the identification of compensation areas (or projects) should be made a-priori in the strategic plan. Then, off-site compensations are selected during the negotiation process for the approval of each urban transformation. For example, private developers might be asked to contribute to large interventions directed by the public administration, such as a new public park, a community garden, or a green noise barrier; or to implement small-scale interventions on public spaces, such as planting a certain number of street trees or de-sealing parking areas of a certain size. The scoring system can still serve as a guide to prioritise actions depending on the level of ES demand. In the discussed case, for example, the developers would gain 4 points by de-sealing a parking area in Cluster 1 or 2, but only 2 points if the area is in Cluster 4.

5. Discussion

5.1. Innovative elements of the proposed approach

The paper developed and tested a performance-based planning approach built around the assessment of ES supply and demand in urban areas, thus suggesting a possible way in which scientific knowledge on urban ES can contribute to support decision-making (Posner, McKenzie, & Ricketts, 2016) and to innovate urban planning practices (Ahern et al., 2014). From the planning perspective, the proposed approach adds to the disciplinary debate around performance-based systems, so

far mostly limited to the conceptual level, by adopting an operational lens. While many authors agree that traditional zoning must be overcome and performance-based planning are a promising solution (Ronchi, Arcidiacono, & Pogliani, 2020), the scientific literature has mostly focused on identifying the criticalities revealed by existing applications (Baker et al., 2006; Frew et al., 2016) rather than on developing alternative ways to implement it. The proposed approach has the merit of demonstrating in practice what possibilities are offered by recent methodological and technological advancements, and how they can contribute to develop new forms of performance-based planning systems.

In the panorama of ES research, the proposed approach presents innovative elements with respect to the way ES knowledge becomes an integral part of a plan implementation mechanism. Most of the applications of ES knowledge in planning have focused either on awareness-raising and knowledge co-development (Dick et al., 2017) or on supporting specific decisions, e.g. selecting alternative scenarios or prioritizing interventions (Grêt-Regamey, Altwegg, et al., 2017). Here, the identification of relevant ES as a strategic aspect that the plan should consider is followed by the definition of an implementation tool that ensures their consideration in the negotiation process that leads to the approval of all future urban transformations. By linking the analysis of ES supply and demand to the evaluation process of urban transformations, the proposed approach guarantees the continuous use of ES knowledge as a decision-making support, overcoming the implementation gap that characterizes many ES analyses (Ruckelshaus et al., 2015), especially when an integration of multiple ES assessments is needed (Barton et al., 2018). Moreover, it acknowledges the

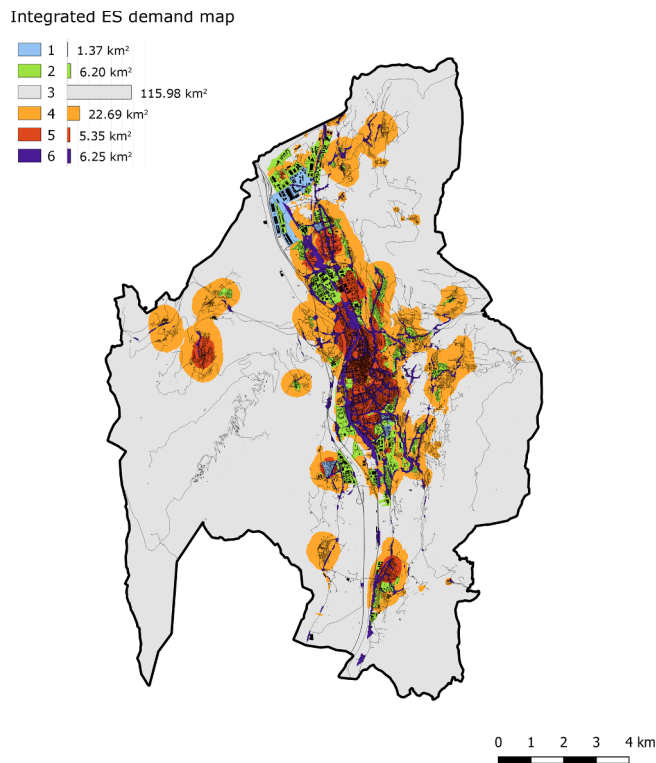


Fig. 5. The “integrated ES demand map” for Trento.

importance of private areas as ES suppliers (Ossola et al., 2018) and ensures coherence between the ways in which ES are treated at the city-wide scale of strategic decisions and at the detailed scale of single properties involved in urban transformations.

5.2. A comparison with existing planning tools addressing green areas and ES in urban transformations

Traditional urban plans based on zoning often include regulations about the share of green spaces or permeable areas that should be maintained in the different zones. However, these quantitative measures are unable to differentiate between different qualities of green (Ronchi et al., 2020) and to value the different ecological functions and ES that are provided by different types of green infrastructure components (Cortinovis & Geneletti, 2019). In the last years, however, some cities have developed more advanced tools, which try to go beyond the most common quantitative indicators and to acknowledge and measure the ecological value of different green areas.

In Berlin, for example, the Biotope Area Ratio was introduced as an environmental indicator specific for urban areas already in the late ‘80s (Lakes & Kim, 2012). It measures the ecologically-effective surface in each land parcel as a weighted sum of the areas covered by different urban green elements. The weights are explicitly based on the different capacity to support a range of selected ecosystem functions, including evapotranspiration, air pollution retention, stormwater infiltration and storage, conservation of soil functions, and biodiversity support (Landschaft Planen, Bauen, & Richard, 1990). Targets of the Biotope Area Ratio were defined to ensure minimum ecological standards for new constructions and redevelopment sites, and became legally-binding at the property level since the ‘90s for the areas included in landscape plans, i.e., large scale development plans in highly-sealed urban areas (Lakes & Kim, 2012). Ease of calculation and flexibility of the structure, which allows modifying the types of urban green elements and respective weights according to locally-specific conditions and needs, have determined the popularity of the Biotope Area Ratio. Similar tools have been adopted or are being tested in Seoul, Helsinki, Seattle,

Southampton, Washington DC, Singapore, and London (Green Infrastructure Consultancy Ltd, 2018; Juhola, 2018; Lakes & Kim, 2012).

These tools demonstrate a clear advancement with respect to common standards for green or permeable areas included in most urban plans. However, a limitation is that they only look at ES supply, i.e. at the functions that the green elements included in the transformation must provide, but do not consider the demand, i.e. how much is needed in the different parts of the city. Based on a comparative analysis of the Biotope Area Ratio in Berlin and Seoul, Lakes and Kim recommend that, in the future, target levels should consider not only overall criteria such as land use and type of development of the urban transformation, but also local aspects such as degree of built area in the different contexts (Lakes & Kim, 2012). More advanced in this direction is the Green-Blue Factor implemented in Oslo, which is characterised by differentiated target values in different parts of the city depending on the density of the area (Horvath, Barton, Aukrust, Halvor, & Ellefsen, 2017; Oslo kommune, 2018).

By building on the ES concept, the proposed approach includes ES demand in a clearer and more explicit way. The adopted mapping methods account for the multiple factors that determine the demand for different ES, providing a more detailed picture compared to population density maps, especially in the case of regulating ES that also depend on locally-specific environmental conditions (Cortinovis & Geneletti, 2019). The “integrated ES demand” map, which clusters areas in the city based on their different profiles of ES demand, is an innovative and potentially very useful tool for urban planning, since it allows identifying priorities and targeting interventions, thus increasing the benefits generated by the creation of new green areas. Coherently with this benefit-oriented perspective, the proposed approach can be seen as mainly an “out-of-kind” compensation mechanism in which the type of requirements does not depend on what is lost but on what is more needed in each site from a citizen’s perspective.

Following the same rationale, “off-site” measures might also be included in the proposed performance-based approach, as exemplified in one of the testing applications. In that example, we sketched out a potential system controlled by the municipality, where only localized off-site interventions in public areas are allowed. A wide range of other, more complicated mechanisms exists to govern off-site compensations (Vatn, Barton, Lindhjem, Movik, Ring, & Santos, 2011), some of which could – in principle – be integrated in the proposed performance-based approach. These include mechanisms based on a generalised transfer of ecosystem-based actions across the whole municipal area, on the model of transferable development rights, a quite common planning instruments in Italy (Falco & Chiodelli, 2018). While discussing the pros and cons of such options is not the aim of this article, we highlight here that these options entail different implications in terms of costs, management, and equity in the distribution of benefits across the city (Vatn et al., 2011). If making urban interventions in areas with no demand to compensate off-site by enhancing public spaces is a way to direct actions where they can produce greater benefits, the same might not true for more generalised mechanisms, which could even contradict the principles on which the whole approach is based. Decision-makers must be aware of such implications when selecting the most suitable mechanism to apply in each city.

5.3. Strengths and limitations

The testing application to the city of Trento revealed some strengths and limitations of the proposed performance-based planning approach. Starting from the methods adopted for ES mapping and assessment, each of them is characterised by specific limitations: for details we refer to the descriptions in the [Supplementary Material](#) and to the literature cited therein. Here we focus on more general issues related to its use as a policy instrument in the planning process.

The proposed approach shares with other performance-based

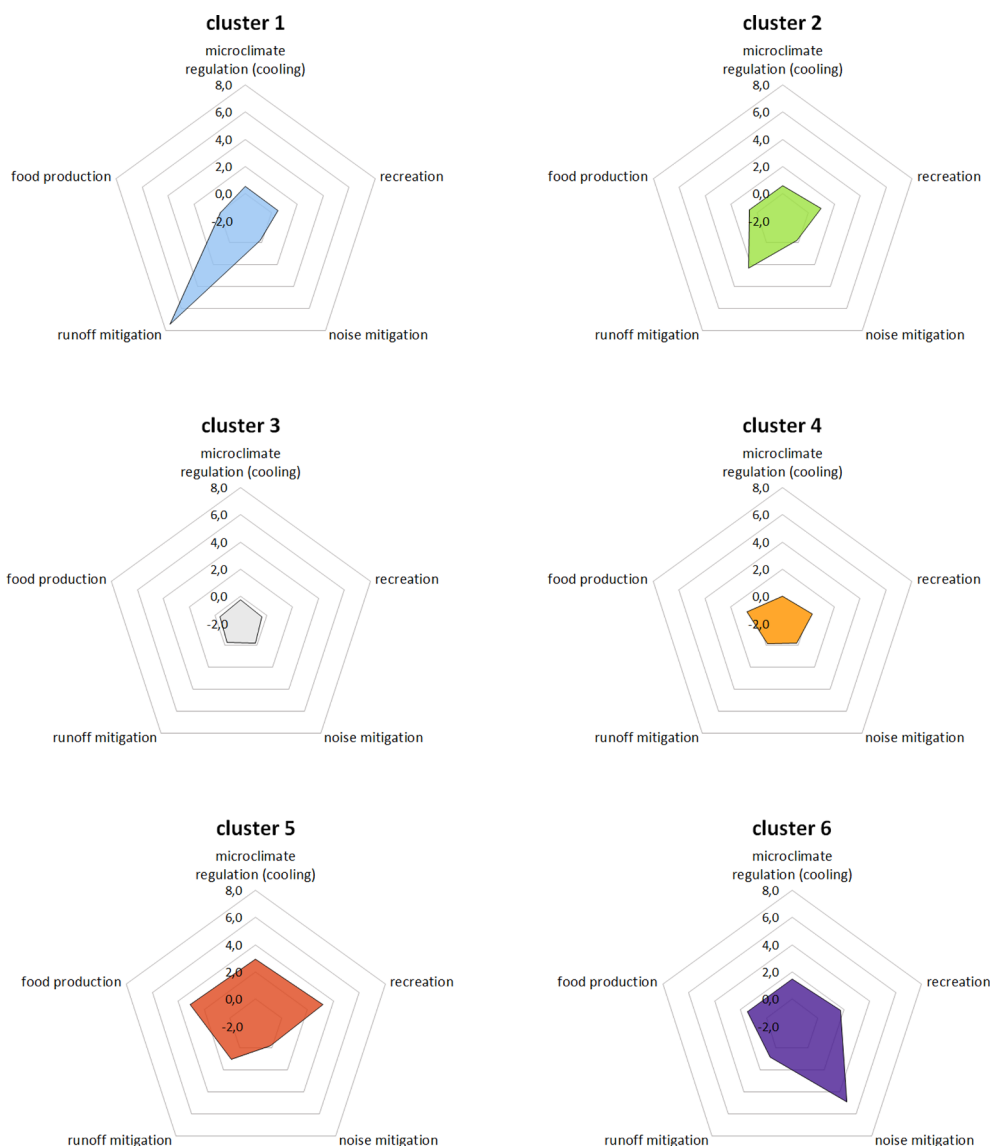


Fig. 6. Profiles of ES demand across the six clusters. The spider graphs show the Z-score (i.e., distance between the average value of the cluster and the global mean, expressed in terms of standard deviations), which corresponds to the different scores assigned to ecosystem-based actions (see Table 4).

approaches the capacity to define locally-specific requirements while avoiding over-prescriptive or excessively complex zoning regulations. At the same time, it is transparent and rational. The rationale of the mechanism, i.e. balancing the negative impacts with positive contributions, is easily understandable by all parties involved and the maps of ES supply and demand are combined in a clear and replicable way. The “combined ES supply” and the “integrated ES demand” maps could be made available to all citizens for consultation through a web-GIS platform. This would make it possible for everyone to run the first stage of the process, i.e. the “desk-based assessment” of the required

performance (see Fig. 1), thus enhancing the transparency and the legitimacy of the tool. These strengths are particularly relevant considering that, as all other performance-based approaches, the process includes a negotiation phase between the private developers and the public administration, but here, unlike other approaches, the negotiation process do not involve a discussion of the requirements. These are defined a-priori based on the “combined ES supply” map, and the negotiation stage only evaluates the quantity and quality of the proposed ecosystem-based actions in terms of consistency to the requirements, adequacy to the size of the intervention, and expected efficacy. This

Table 5

Scores associated to ecosystem-based actions targeting each of the five selected ES in the six clusters. Scores range from 0 to 4 (see Table 4). In brackets, Z-scores measuring the distance between the average value of the cluster and the global mean, expressed in terms of standard deviations (see Fig. 6).

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
Noise mitigation	0 (-0.2)	0 (-0.2)	0 (-0.2)	0 (-0.2)	0 (-0.2)	4 (4.9)
Microclimate regulation	1 (0.6)	1 (0.6)	0 (-0.3)	1 (0.0)	4 (2.9)	3 (1.5)
Runoff mitigation	4 (7.4)	4 (2.3)	0 (-0.3)	0 (-0.1)	2 (1.0)	2 (0.8)
Food supply	0 (-0.1)	1 (0.6)	0 (-0.4)	2 (0.7)	4 (3.1)	3 (1.5)
Recreation	1 (0.5)	2 (1.0)	0 (-0.4)	1 (0.3)	4 (3.2)	3 (1.7)

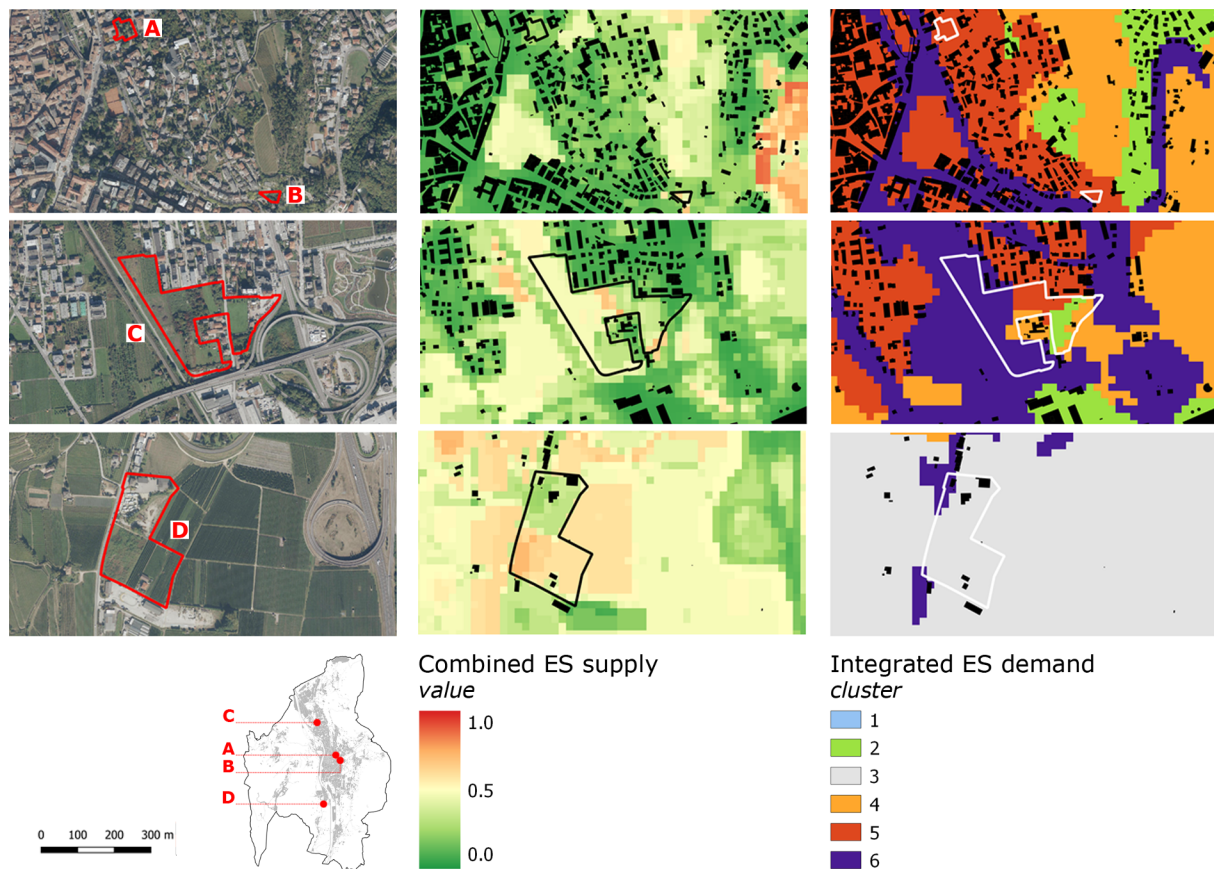


Fig. 7. The four urban transformations (Sites A–D, see text) selected to test the proposed approach in Trento (left panel) and their “combined ES supply” (central panel) and “integrated ES demand” (right panel) maps.

safeguards the key role of the public administration in ensuring the protection of the public interest, but at the same time prevents the process being perceived as uncertain and erratic, as it was the case in previous applications of performance-based approaches.

Considering its potential applicability and transferability to other contexts, one of the main strengths of the approach is its flexibility. We described an illustrative application to Trento, where relevant ES have been selected based on the existing planning documents and weighted equally to produce the synthesis maps. However, the ES can be different (e.g., the demand for habitat provision by selected species, such as pollinators, could have been included) and weighting factors can be introduced to reflect local conditions and policy orientations about the relative importance of the different ES. Other, non ES-based information could be included as additional factors in the assessment process, for example as a way to differentiate the targets in different areas of the city or to incentivize certain interventions. On the other hand, the ability to tailor the requirements to the expected impacts of the urban transformations and the specific needs of the surrounding area comes at the cost of complexity, thus also increasing transaction costs. The proposed approach is more complex than the other approaches under experimentation in some cities across the world and requires a higher amount of information to be processed. While from the technical point of view this complexity can be overcome by an automatized generation of the maps through a GIS software, the administration of the process requires all parties involved to be trained and to share a common understanding of how the process works. This steep learning curve has been highlighted as a limitation in previous experiences of performance-based planning and should be taken into consideration (Baker et al., 2006). Monitoring the implementation of ecosystem-based actions and updating the input data for the mapping and assessment methods also requires additional efforts and resources compared to more traditional implementation tools.

Some underlying critical conceptual aspects also deserve to be discussed and explored in their practical implications. The scaling of the ES supply and demand values to a common range implies a differential valuation where marginal changes in ES with large variance are undervalued relative to ES with low variance. The scoring system and the thresholds assigned to impact classes (Table 2) and ecosystem-based actions (Table 4) have significant consequences in the implementation. For example, we assigned a low required level of performance even to areas with no current ES supply (Table 2), so that every urban transformation contributes to enhance the current condition. Assessing the demand based on the current population or the expected new inhabitants produced by the planned transformation also has an impact. Our choice was based on the low degree of implementation of previous plans and on the assumption that the new interventions should take care of the additional needs that they generate, independently of how they compensate for the negative impact on ES supply. However, in a real-life implementation of our proposed approach, these implicit valuations, as well as the underlying assumptions and objectives, need to be made explicit and subject to political validation.

The same applies to the assessment of the expected impact on ES supply through the “combined ES map” where individual ES values are summed. The method implicitly assumes that a complete trade-off among the considered ES is accepted, i.e. one ES can completely substitute another ES. Weighting factors can be added, as previously discussed, but no lower boundaries are set within the approach to safeguard the current ES provision. This requires a careful preliminary assessment of where urban transformations should not be allowed at all and the definition of other tools to safeguard the provision of ES that need to be preserved, to avoid the unintended consequence that the flexibility of performance-based planning prevents local government to ban urban development in valuable areas (Frew et al., 2016). In the

case of Trento, for example, the selection of relevant ES mostly focused on urban ES, hence most forest areas were characterised by low values in the “combined ES supply” map. However, this does not imply that urban interventions are favoured in those areas, considering that other policy instruments are already in place to prevent urban development within forests. Evaluating the potential effects of implementing the proposed approach in the light of concurrent (sectoral) policies and regulations, and comparing them to alternative options, is beyond the scope of this study. Further research in this direction would help to understand to which extent the gains in terms of a better distribution of ES counterbalance the higher costs.

6. Conclusions

In this paper, we developed an innovative performance-based planning approach built around the assessment of ES supply and demand. We assumed the enhancement of relevant ES as the overall objective of the urban plan and derived potential requirements against which urban transformations could be evaluated. We linked the required level of performance to the expected negative impacts of the urban transformation on the current ES supply, and the required type of performance to the ES demand. To operationalize this approach, we developed two potential implementation tools: the “combined ES supply” and the “integrated ES demand” maps, and a scoring system that, based on the values of the indicators in the two map, assesses the ecosystem-based actions implemented in each urban transformation.

We tested the proposed approach in the city of Trento, Italy, considering seven urban ES and simulating the application to three different types of urban transformations included in the current urban plan. The application revealed strengths and limitations of the proposed approach and the potential for its adoption as a planning tool. Although further advancements and refinements are still needed before the approach can be integrated in real-life planning processes, we offered a proof-of-concept that can be adjusted and tested in other contexts.

CRedit authorship contribution statement

Chiara Cortinovis: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization. **Davide Geneletti:** Conceptualization, Methodology, Investigation, Writing - review & editing, Supervision.

Reference Data

Data available in data repository Mendeley at [10.17632/nmzdhn9rbd.1](https://doi.org/10.17632/nmzdhn9rbd.1).

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Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.landurbplan.2020.103842>.

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