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A decision-making framework for promoting the optimum design and planning of Nature-based Solutions at local scale

Teodoro Semeraro[a], Elisa Gatto[a], Luigi De Bellis[a], Andrea Luvisi[a], Rohinton Emmanuel[b], Riccardo Buccolieri[a]

[a]Department of Biological and Environmental Sciences and Technologies, University of Salento, S.P. 6 Lecce-Monteroni, 73100 Lecce, Italy

[b]The Research Centre for Built Environment Asset Management (BEAM), Glasgow Caledonian University, Cowcaddens Rd, Glasgow G4 0BA, UK

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Highlights

• Urban ecology must consider green spaces and infrastructure as a single integrated ecosystem

• A framework of urban ecosystem services is proposed to support decision-making processes

• Microclimate regulation of the urban ecosystem is a priority service for human well-being and health

• Human comfort is a useful eco-physiological index to evaluate urban scenarios

Abstract

Urbanization is a key driver of land use/land cover changes climate change. It produces a reduction in natural capital with alteration to the energy budget of land, air ventilation and land surface temperature. The urban morphology derived from the combination of natural capital and human-derived capital is important in urban ecosystem services (UESs) provisioning to mitigate the Urban Heat Island (UHI) effect. Here we report a decision-making framework starting from an applicative case study to assess UESs and promote the best design and planning of Nature-based Solutions (NbS) at local scale. The human thermal comfort has been chosen here as a surrogate to estimate climate regulation as a priority UES in mitigating UHI. The analysis of human thermal comfort in different urban neighbourhood planning scenarios of a city located in Southern Italy has been carried out using the microclimate model ENVI-met. The analysis has been developed to highlight the variation in human thermal comfort in terms of Physiological Equivalent Temperature index (PET) between past agricultural scenarios (no longer more present), current state and several proposed urban scenarios. Such new scenarios have been developed by considering different building arrangements according to municipal planning rules of the city and choosing different types of NbS composition and structure. The analysis has allowed to identify the best scenario characterized by the presence of a community garden with olive groves and estimate the capacity of

NbS to reduce the human thermal comfort by about 3.5ºC and improve the PET in selected locations within the current state. In accordance with the aim and topics of the Special Issue, this study shows how such a framework can be useful to support decision-making processes in choosing the best strategy in terms of urban plans and thus making the urban transformation process more sustainable, contributing to assessing the global targets of the 2030 Agenda at local scale.

Keywords

urban ecology; landscape and urban planning; Nature-based Solutions; human thermal comfort; human health; climate resilience; Strategic Environmental Assessment (SEA)

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1. Introduction

The urbanization process produces land cover and land use changes for the creation of housing, mobility infrastructures, facilities and industries (Moazzam et al., 2022, Estoque et al., 2017), producing loss of agricultural area and biodiversity, natural resources impoverishment and greenhouse gases emissions with negative effects on human wellbeing (Nuissl et al., 2009, Ahern et al., 2014, Zhou et al., 2021). The main consequence of land cover and land use change is a negative effect on the land energy budgets with an increase in heat-absorbing surfaces and a reduction of evapotranspiration (Maggiore et al., 2019, Tong et al., 2017, Xue et al., 2017, Zhou et al., 2021). Moreover, the urban morphology leading to complex airflow patterns and anthropogenic heat release contributes to the increase in air and surface temperatures compared to the surrounding rural area, known as Urban Heat Island (UHI) (Oke, 1980, Ketterer and Matzarakis, 2016, Paramita et al., 2022). The UHI increases with the growth of urbanization processes (Rizwan et al., 2008) that produce land cover changes from free space (natural or agricultural land) to the high density of urban structures, such as buildings, roads, paved squares etc. The UHI is mostly due to the increased heat-absorbing surface, the increase in heat production from anthropogenic sources, the stagnation of heat and the reduction of vegetation evapotranspiration (Harlan and Ruddel, 2011, Qiu et al., 2013, Hirano and Yoshida, 2016). For example, in Glasgow (UK), historic industrialization and enduring land cover changes, despite the decline in population and anthropogenic heat, have led to an all-year UHI of over 3.0 oC (Emmanuel and Krüger, 2012, Emmanuel and Loconsole, 2015; Kruger et al., 2018). Emmanuel and Krüger (2012) showed, for example, that the most urbanized location has highest minimum temperature for the day, in striking contrast to the site with the least built-up area (Glasgow Airport).

Changes to human thermal perception due to the UHI effect are clearly visible (Oertel et al., 2015) and, together with heatwaves, primarily pose a danger to vulnerable individuals such as the elderly, very young, those with social or physical impairments, or those unable to afford mitigation measures (such as air conditioning) (Nouri et al., 2018, Sharafkhani et al., 2018, Dastoorpoor et al., 2021). Further, the land use and land cover change generated by urban growth has to be avoided and reduced because it represents a significant ecological space transfer from natural to built capital altering biodiversity, natural resources and biogeochemical and biophysical flows (Tan et al., 2020). However, it is not possible to avoid it totally because it supports the increasing world population and its flow from rural area to cities (Mitchell, 2012). Currently, 56% of the world global population is concentrated in urban areas (Demographia, 2020, Paramita et al., 2022) and the UN estimated that this value could increase in the future up to 70% in 2050 (United Nations, 2014). Currently, European Union increased from 429 million to 447 million, with a growth of 4% Between 2001 and 2020, the population of the EU (Eurostat, 2023), with an increased in residential areas (Copernicus, 2023 (Fig. 1).

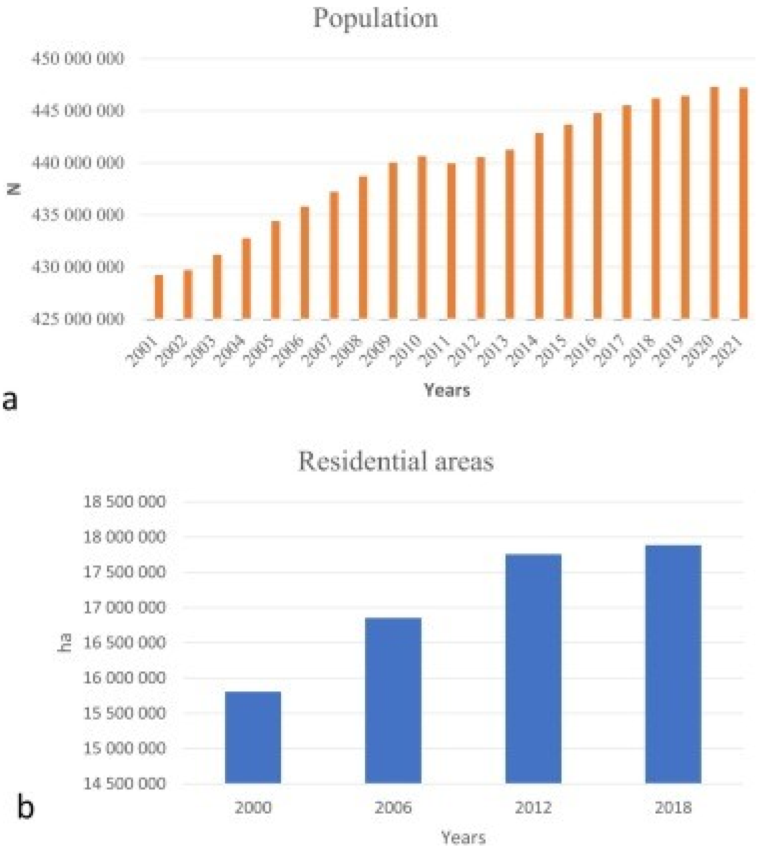

Fig. 1. a) Residential population in EU (Eurostat, 2023); b) Residential area in EU (Copernicus, 2023).

Mitigating negative consequences of land use and land cover change through the Agenda 2030 Sustainable Development Goals (SDGs) has become the primary purpose of urban planning policy involving scientists, public administrators, civil society, and the private sector (UN Habitat, 2015, Nicolaides, 2021). In this context, Natural-based Solutions (NbS) represent the basic strategies to make Europe more climate-resilient and support important European Union policies such as the European green Deal, Biodiversity Strategy, and climate adaptation strategies (NbS research policy - European Commission, 2022). NbS support urban natural capital by introducing ecological structure and functions able to produce direct and indirect benefits for human-wellbeing in the urban boundaries (Morgenroth et al., 2016, Di Sabatino et al., 2015, Jeanjean et al., 2017, Buccolieri et al., 2018, Gatto et al., 2020, Hegetschweiler et al., 2022, Frantzeskaki et al., 2022). These benefits are called urban ecosystem services (UESs) (Costanza et al., 1997, De Groot et al., 2010, Tan et al., 2020, Semeraro et al., 2021a). Tan et al. (2020) discussed two visions of UESs regarding "ecology in city" or "ecology of city" (MEA, 2005). The former focuses on UESs generated by natural and seminatural areas intended as ecosystems within urban boundaries. Interpreting this definition in an applicative way, the urban element and natural capital could be planned and assessed in a separate way as distinct elements of the urban area. This definition allows the value of UESs to be considered independently from the built capital. This could lead to disregarding the synergies generated by different plan configurations of natural capital and building capital in urban morphology (Gomez-Baggethun et al., 2013; Pauleit et al., 2019; Anderson et al., 2021). Some studies have shown a good relationship between urban morphology and urban warming mitigation and others have highlighted different capacities of dwellers to use natural and semi-natural elements or to get benefits from them (He et al., 2020a, He et al., 2020b, Taylor et al., 2020). Therefore, different urban morphologies characterized by the same composition of natural capital and built capital but with different configurations can produce different amounts of UESs, perceptions and capacity to be used by dwellers. On the other hand, the second vision of UESs focuses on urban areas intended as an urban ecosystem where the UESs encompass all range of services provided by human capital and natural capital. This highlights a holistic vision of UES derived from the combination of natural capital with built capital. In this way, NbS in the cities is not just designed to fill empty spaces between buildings for aesthetic value or social activities, but rethought in terms of urban morphology to create an urban pattern able to maximize their UESs (UN-Habitat, 2015; Semeraro et al., 2020; UN, 2021; Frantzeskaki et al., 2022; Mahmoud et al., 2022).

There is no 'correct' ecological vision applicable to urban planning and design, but they have to be balanced considering the specific context and aim of urban planning (Tan et al., 2020). For example, to mitigate UHI, the physical condition of the environment is important because the physical structures of the abiotic and biotic components can change solar radiation, ventilation and the land surface energy budget (Yang et al., 2019a). In this case, combining natural capital with built capital is fundamental to determining urban microclimate. Therefore, the design of NbS needs a careful assessment of UESs for studying the interplay between the city, its residents, and ecosystems that have to be sensitive and adaptable to local conditions (Ward, 2010, Robinson, 2016, Wolff and Haase, 2020, Anderson et al., 2021). Many science applications and tools are focused on UESs assessment and mapping rather than their integration into decision-making processes, and only a few frameworks have been developed so far to evaluate the effect of natural capital in UESs provisioning linked to urban planning and design (MAESUE, 2016, Sevianu et al., 2021). Moreover, most of the ESs approaches have been developed at the landscape scale without considering the heterogeneity of the ecosystem biophysical structure and functionality generated by the combination of biotic and abiotic components at the local scale (Burkhard et al., 2013). Indeed, UESs must be implemented by planning and designing NbS considering the context of the urban area and the priority of human well-being to achieve (Chenoweth et al., 2018, Escobedo et al., 2018, Semeraro et al., 2021b, Tan et al., 2020).

The implementation of a systematic framework to integrate UESs assessment in the local decision-making processes currently represents a gap in knowledge and applicative approaches (Richards et al., 2019, Wellmann et al., 2020, Grace et al., 2021). Such a gap can be overcome with the transferability of applications between single case studies, and applying transdisciplinary approaches to evaluate UESs derived by urban ecosystems considering the feedbacks between natural and built capitals and the urban social-economic context determining who benefits from ESs and which benefits are important for human liveability (Balzan et al., 2021).

In this context, the aim of this paper is to develop a framework of analysis that includes both the assessment of UESs able to support decision-making processes to enhance the livability of urban patterns under UHI and the quantification of the improvement of human well-being by planned NbS. Here, the analysis is focused at the local (neighbourhood) scale, since it represents the minimum extent of the urban planning and growth that in a holistic vision defines the final puzzle of the cities (Piracha and Marcotullio, 2003, Maggiore et al., 2019, Semeraro et al., 2020). The necessity to plan urban sustainability at the local scale is included in the SDGs (e.g. development of common goods, integrating streets, open spaces with a buildable plot pattern) (UN-Habitat, 2015; Semeraro et al., 2019; Tan et al., 2020). This is in accordance with the aim and topics of the Special Issue "Augmented Nature Based Solutions (NBS) for Cities: Embedding technologies for improving NBS performance and fostering social inclusion in urban greening strategies", aiming at collecting best practices on how technologies can enhance the performance and impact of NbS, with a focus on how to benefit from measuring NBS for developing successful and innovative management and business models of urban green, and support policy making to local government.

The approach of managing land use change connected to the urban expansion is one of the most important challenges that this paper attempts to contribute to by helping to promote SDGs through Urban Planning and Design, establishing the adequate provision of common goods and benefits in urban space. In this study the microclimate regulation is used as a priority UES for planning climate strategies in an Urban Neighbourhood Plan (UNP). To this aim, an analysis of different UNP scenarios considering several NbS configurations and built infrastructure is carried out. The human thermal comfort can give information about heat vulnerability and health risks derived from the human physiological response to microclimate conditions, and it is thus used as a parameter to assess and compare the urban livability in each UNP scenario.

2. Description of the study area

The study area is in the peri-urban area of the city of Gallipoli in Southern Italy, located along the coast of Apulia Ionian Sea (Fig. 2A). Based on the Köppen Climate Classification, the climate of the city is "Csa" (Mediterranean Climate), characterized by very warm summers, due to the domination of subtropical high-pressure systems, and relatively mild winters with moderate and changeable temperatures. The Mediterranean region is potentially vulnerable to climatic changes because it is affected by interactions between mid-latitude and tropical processes, being in a transition zone between the arid climate of North Africa and the temperate and rainy climate of central Europe (Giorgi and Lionello, 2008).

Fig. 2. A) The study area is located in the city of Gallipoli (southern Italy). B) Example of olive trees affected by Xylella fastidiosa bacteria in the study area, C) Study area after the cutting operation of dead olive trees.

The study area has been designed as a new urban development site area within the "urban plan" of the city. For this reason, an UNP has been developed by landowners to start new urbanization processes for creating a new residential area. So, the UNP had to arrange the new urban composition and configuration considering buildings, roads and parks.

The study area is 8.1 ha and was in the past characterized by agricultural vegetation mainly represented by olive groves (3.1 ha), arable lands (4.17 ha) and the presence of low residential buildings and roads that are sealed surface (0.83 ha). The olive trees were monumental plants with trunks characterized by a diameter larger than 70 cm and a sculptor shape as defined in the regional law. Most of these olive trees were protected by Regional Legislation by virtue of their production as well as their cultural and historical value (Bollettino Ufficiale della Regione Puglia – BURP —N. 83, 7 June 2007). The spread of the phytopathogen Xylella fastidiosa in the area caused the death of almost every olive tree; from a visual inspection, the canopy of the trees had completely withered (Luvisi et al., 2017) (Fig. 2B). This led to the uprooting of olive trees including the monumental ones located in the study area without replacing them and the new land cover is arable land waiting for the possibility to develop the new UNP (Fig. 2C). The arable land is now 7,27 ha and is not used for agricultural production, but the main action is vegetation control to reduce the fire risk in the summertime. Only a few parts or arable land were characterized by herbaceous and shrub vegetation not correlated to agricultural activity.

2.1 UNP in the SEA process

In agreement with the Directive 2001/42/EC (2021), the UNP scenarios investigated in the present paper have been subjected to the Strategic Environmental Assessment (SEA) that represents a systematic process for evaluating the sustainable implications of a proposed Policy, Plan or Program (PPP. It represents a process of systematic decision support for landscape and urban planning that includes a range of analytical and participatory approaches aiming to integrate environmental sustainability goals considerations into PPPs (Natcher et al., 2022). In this way, the SEA process provides for the planning of mitigation actions to reduce negative environmental impacts and to improve the quality of human life. It is in fact required to verify whether the environmental sustainability of the objectives fixed in the early phase of PPPs is satisfied by the decision-making choices considering different scenarios of PPPs and interactions at different scales or institutional levels. Thus, the SEA process follows all development phases of the PPPs to drive public and private decision-making in industry, professional organisations, and policy makers (OECD, 2006, Semeraro et al., 2020).

The ES concept is not intrinsic to the SEA process and is still at an exploratory phase has difficulty to find its application in decision making processes (Baker, 2013; Semeraro et al., 2021; Slootweg, 2021). A critical analysis of the applications in case studies, each highlighting specific SDGs, can help improve the SEA guidelines developed by international organisations (Geneletti, 2016, Semeraro et al., 2020).

In the context of the present study, one phase of the SEA process has been the cooperation of the environmental and landscape conservation agencies (co-planning). In this phase, the agencies suggested modifications and submit specific integration in the original district plan to improve sustainability. This allows the planner to produce different UNP scenarios which are here evaluated to propose the best ones increasing the livability of the study area.

3. Methodology

In this study, we analyse the provisioning of climate regulation of the vegetation as a priority ES to identify the best UNP scenario able to mitigate the microclimate impact of land use and land cover change and to increase the human well-being. So, the livability of the urban neighbourhood derived from a combination of “human-derived capital” and “natural capital” has been investigated by analysing the human thermal comfort (Ketterer and Matzarakis, 2016, Cai et al., 2022, Paramita et al., 2022). The study has involved two phases following the conceptual framework proposed by Tan et al. (2020) (Fig. 3):

- Phase 1 includes the characterization of the study area where different UNP have been developed. This phase is important to define the main natural, economic and cultural aspects of the landscape context that have to be included in the developing processes of the UNP (UNEP, 2004; Geneletti, 2016). The UNP scenarios have been here developed considering the social and economic interests of the landowners of the study area and the possibility to develop natural capital to enhance climate regulation as priority ES. The natural capital implementation has been based on the design of NbS that include the implementation of co-benefits without compromising the priority ES (Semeraro et al., 2020). The land use and land cover in the UNP scenarios have been designed following the municipal and regional norms, as well as the environmental laws. Therefore, the built capital and natural capital configuration and composition in the UNP scenarios have been developed changing the buildings shape and vegetation type and clustering in NbS;
- in Phase 2, the priority UES change has been assessed through the analysis of human thermal comfort generated by the different UNP scenarios (Mayer et al., 1987; Binarti et al., 2021, Binarti et al., 2022; Manavvi and Rajasekar, 2022). The human thermal comfort has been analysed only for summertime considering the climate condition of the study area. Details about each phase are given below.

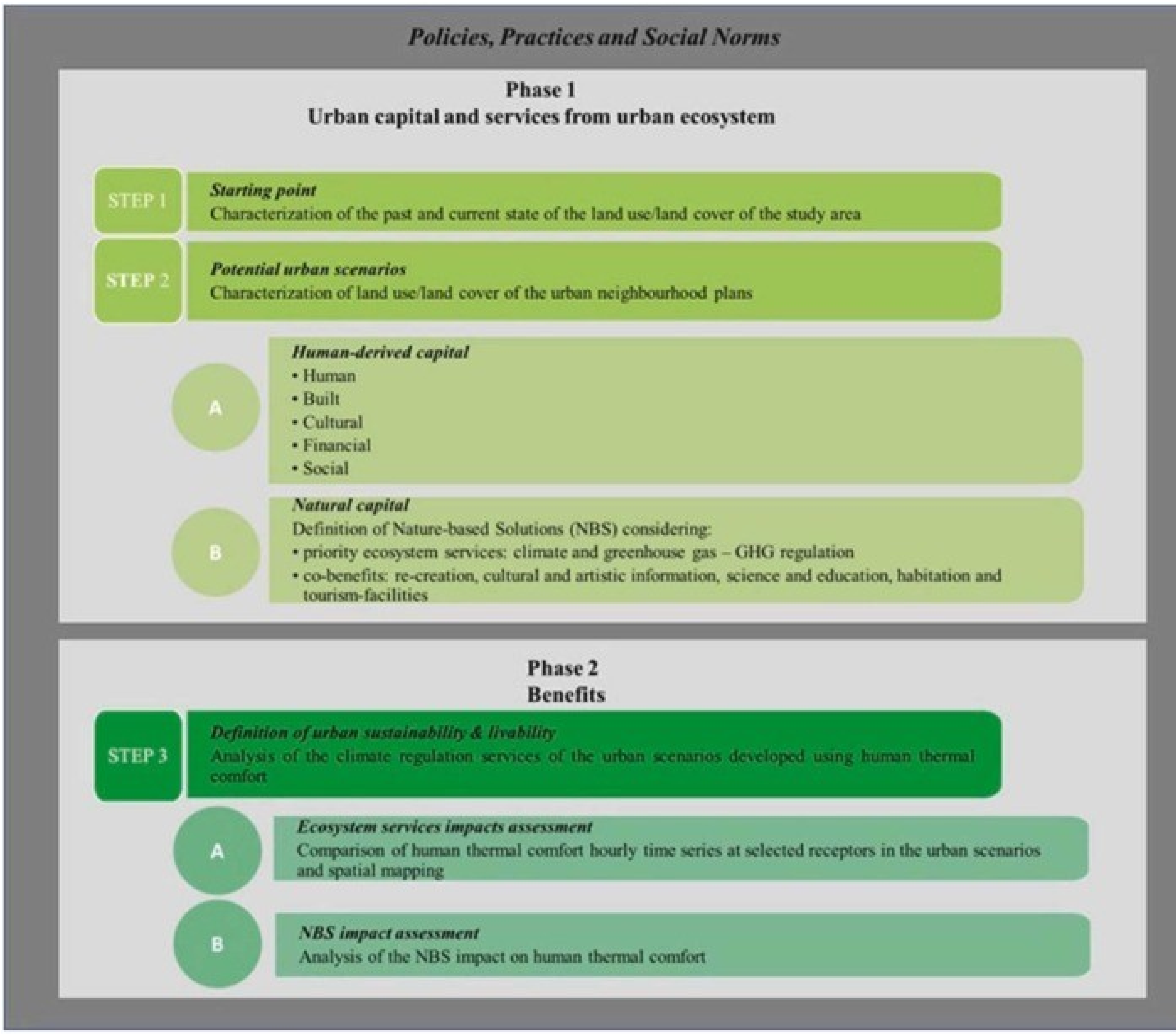

Fig. 3. The study framework followed in this paper and inspired by Tan et al. (2020).

3.1. Phase 1: Urban capital and services from urban ecosystem

Several UNP scenarios have been derived from the social and economic choices of the landowners in the study area, landscape context of the area, and the policies, practices and social norms at the regional and municipality level that drive urban planning processes. Moreover, the UNP scenarios are the result of the integration of scientific and technical knowledge with social and institutional norms. This together could be intended as human-derived capital involved in urban planning processes (Tan et al., 2020). The UNP scenarios have been developed considering the neighbourhood as an urban ecosystem, but NbS in the open space has been designed considering the characteristics of potential vegetation of the landscape context and cultural aspects of the agricultural area.

Based on the compiled data, a series of scenarios have been developed to assess how the development of green space, infrastructure and building composition might affect the Physiological

Equivalent Temperature (PET) index value, here employed to evaluate the thermal comfort (Natcher et al., 2022).

Mainly, in the study area, the building and infrastructure composition have been suggested by the interaction between planners and public agencies in the SEA processes. Instead, in this study, vegetation composition has been proposed to be able to improve the PET. Some scenarios proposed have been set to increase also the social and cultural benefits as a co-benefit of the NbS proposed (Mell et al., 2009; Semeraro et al., 2020, Tzoulas et al., 2020). Therefore, the potential to use agricultural vegetation has been considered for mitigating PET, while also employing the green space as community garden. All the scenarios investigated here are summarized below:

- reference scenarios (scenarios A and B): the UNP actions started before that Xylella fastidiosa destroyed the olive groves in the study area (Semeraro et al., 2020), therefore the starting reference scenarios are agricultural ecosystems with the presence of some residential buildings: specifically, an agricultural ecosystem characterized by olive groves with monumental olive trees (scenario A, corresponding to the past scenario) (Fig. 4 A) and a scenario replacing olive groves with arable lands (scenario B, corresponding to the current scenario) (Fig. 4B). The current scenario has been chosen as the expected evolution of the study area by the Xylella fastidiosa spread which is the main driving force that pushed the land cover changes from olive groves to arable land (Saponari et al., 2017, Maggiore et al., 2019). Land use and land cover maps for these two scenarios have been created by the digitization of the 2016 regional orthophotos and field samplings;

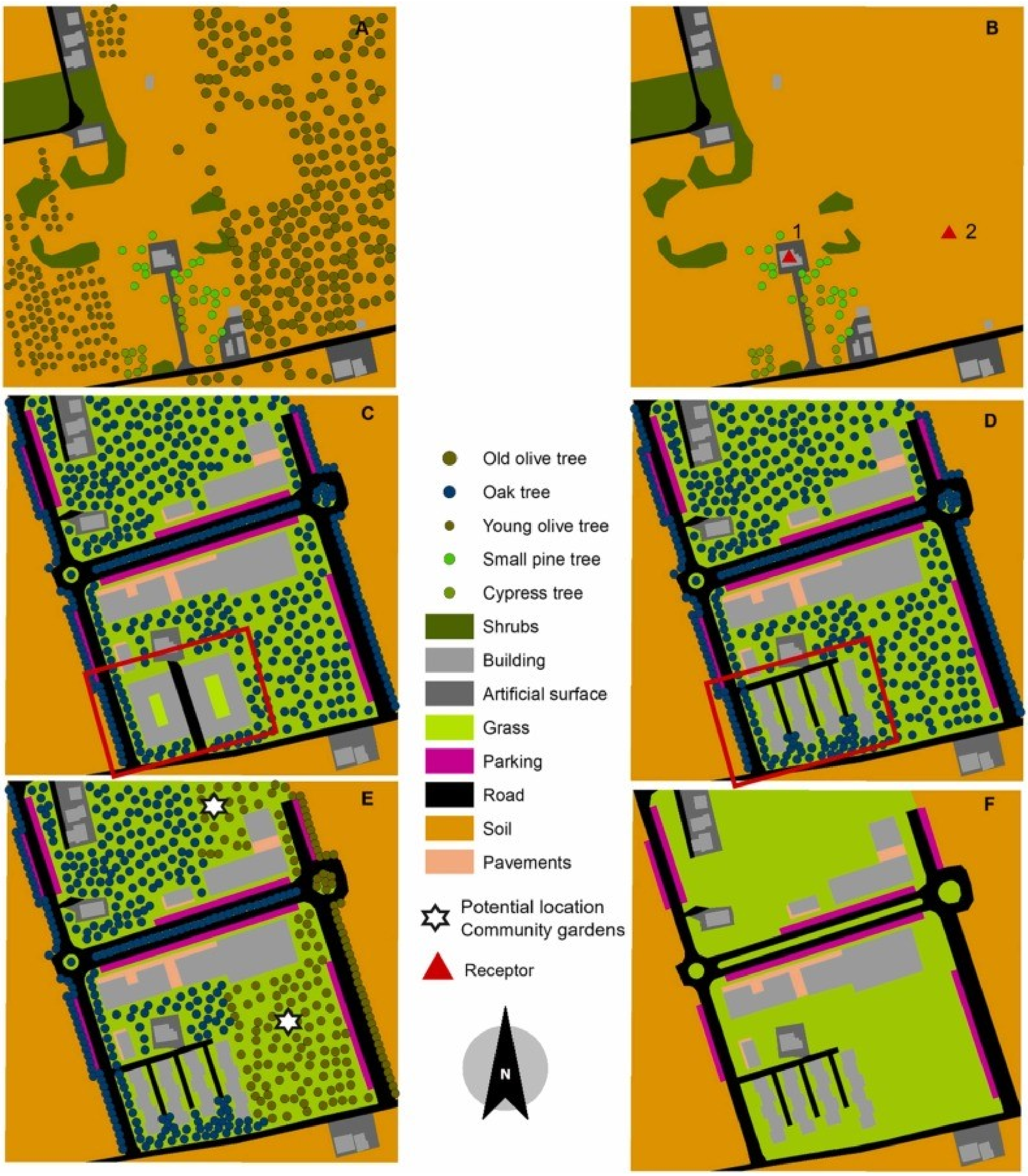

Fig. 4. Scenarios investigated: A) past scenario to analyse the potential effect of monumental olive trees on microclimate regulation; B) current scenario to evaluate the microclimate regulation of current status of agricultural ecosystem, with indication of the position of receptors used in all the scenarios investigated for evaluating the PET index; C and D) two UNP scenarios in which olive trees are replaced by oak and that differ from urban morphology in red square; one proposed by the experts in the first step of design activity (C) and the second derived by co-planning action with the public environmental agencies (D); E) UPN scenario that starting from the D) scenario proposes the realization of community garden in urban parks partially restoring olive trees in the study area; F) UNP scenario considering only grass vegetation instead of trees.

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- the first UNP scenario (scenario C) has been developed considering the prescriptions of the urban municipal plan of Gallipoli city. However, the total planned volume (cubic meters) for the construction of new buildings is less than that of the urban municipal plan to reduce the land use/land cover transformation. This allowed us to increase the green area. At first, this has been necessary to keep the maximum number of monumental olive trees in the area because the urban planning activities started before the death of monumental olive trees. Main roads have been planned in consideration of the track prescriptions provided by the urban municipal plan developed at city level. The olive trees destroyed by Xylella fastidiosa have been replaced with oaks trees considering the potential natural vegetation of the area respect to the context of reference and trying to develop forest vegetation useful for thermal comfort (Blasi, 2010) (Fig. 4 C);

- the second UNP scenario (scenario D) has been developed considering the feedback from the Regional Landscape Agency (co-planning action between private and public institutions) to change the shape of two buildings to reduce the landscape view impact. Here, two buildings have been replaced with four buildings changing the shape and reducing the total surfaces (Fig. 4D);

- the third UNP scenario (scenario E) has been envisaged community gardens in the areas previously occupied by monumental olive trees, replacing dead olive trees with new ones resistant to the pathogen and integrating oak in the other parts. This could be a good strategy to recover the past cultural value of the area in agreement with the urban development (Fig. 4E). Furthermore, it could enhance ESs linked to re-creation, cultural and artistic information, science and education, habitation and tourism-facilities derived by land use and land cover planned in coherence with the past scenario (Miller et al., 2019; Taylor and Lovell, 2013).

- the fourth UNP scenario (F) considered only grassland as the main vegetation in UNP. It was realised as a reference scenario to evaluate the effects of NbS in the best scenario derived by simulation in improving microclimate regulation services and improving human thermal comfort (Fig. 4 F).

- Two receptors were selected to investigate the PET hourly time series in all the scenarios investigated. The first receptor was positioned on the roof of an existing building and allows to assess the impact of UNP scenarios on humans that already live in the study area. The second receptor was in the urban park area. It was chosen to assess the livability of the free area planned for social and cultural activities (Fig. 4B).

3.2 Phase 2: Definition of urban sustainability & livability

The human thermal comfort is analysed using the PET, which quantifies thermal conditions generated by the energy balance of humans with a given environment (Hoppe, 1987). It is one of the most useful indices employed to analyse human thermal comfort in the urban area because it can be linked to human heat stress due to high temperatures (Chen, 2012; Yang et al., 2019b; Davtalab et al., 2020; Binarti et al., 2021, Binarti et al., 2022; Cai et al., 2022; Manavvi and Rajasekar, 2022; Paramita et al., 2022).

The ENVI-met tool has been employed to obtain the PET index in each scenario generated. ENVI-met is a prognostic non-hydrostatic model for the simulation of surface-plant-air interactions composed by a 3D main model and, in addition, a one-dimensional (1D) atmospheric boundary layer (ABL) model (Semeraro et al., 2021c, Binarti et al., 2022). It is an efficient tool in predicting the interaction between plants and the atmosphere condition in the complex urban context. It includes the 3D vegetation model useful to setting the different biophysical structure of the green areas, therefore it is useful to assess the interactions between different type of vegetations and surrounding environment, included build area (Roth and Lim, 2017, Tsoka et al., 2018, Binarti et al., 2022). The capacity of ENVI-met to work in microclimate simulation in the Salento area was tested in different local studies (see for example Gatto et al., 2020).

The simulated study area dimension is 300 m x 300 m, discretized using a grid of 170 cells (x axis) x 170 cells (y axis) x 25 cells (z axis). The lowest size of the cell along the z axis (close to the ground) has been split into 5 sub-cells. Seven nesting grids have been used to minimize errors in the simulation improving output data. Hourly air temperature (Tair) and relative humidity have been forced at the model boundary to drive the simulation with meteorological input obtained from a 10 m high Regional Agency for Environmental Protection ARPA-Puglia meteorological station located 30 km far from the study area (ARPA-Puglia, 2022). The analysis allowed us to build profiles of Tair and relative humidity of a typical (average) day for the period 1 July - 31 August 2021 and select two prevailing winds (the first characterized by wind velocity of 2.4 m/s and direction of 225º; the second wind velocity of 1.9 m/s and direction of 270º). The cyclic-type method has been selected for the lateral boundary conditions (LBC) has been employed. For each case, ENVI-met has been run for a 16 h period, starting at 06:00. Details about initial and boundary conditions used in ENVI-met simulations are collected in Table 1.

Table 1. Initial and boundary conditions used in EVI-met simulations.

Parameter	Definition	Value
Simulation Time	Start Date	01 July 2021
	Start of simulation (h)	6:00
	Total simulation time	16 h (5 h spin-up + 11 h)
Meteorological conditions	Wind speed (m/s)	2.4 - 1.9
	Wind direction (°)	225 - 270
	Air temperature T (forced) (°C)	Daily profile (Tmax=33.8; Tmin=24.7; Tmean=29.3)
	Relative humidity RH (%) (forced)	Daily profile (RHmax=76; RHmin=42; RHmean=59)
	initial temperature (K) and relative humidity (%) of deep layer below 0.5 m	293–60 (default values)

Parameter	Definition	Value
Computational domain and grid	Grid cells (x,y,z)	170 × 170 × 25
	δx x δy x δz	2 m × 2 m × 2 m (equidistant: 5 cells close to the ground)
	Nesting grids	7
	Boundary conditions	Cyclic

The characteristics of the vegetation used in the past and current scenarios have been obtained from field measurements and canopies digitization using orthophotos. For the UNP scenarios C, D, E and F the vegetation models have been determined analysing similar urban and landscape contexts.

4. Urban Sustainability & Livability: thermal comfort results

In this section, we analyse the thermal comfort in terms of PET obtained from ENVI-met simulations within the whole study area and at the two receptors 1 (6 m high) and 2 (1.6 m high) (shown in Fig. 3B). The priority ES has been defined considering the beneficiaries, i.e. dwellers of the future neighbourhood. In this case, we expect it is important to evaluate the human thermal comfort to improve the livability of the dwellers.

4.1. 270º wind direction

Considering the 270º wind direction, the analysis shows that the scenario E (with NbS consisting of urban forest and community gardens realized with olive trees) is the best one in terms of improvement of thermal comfort and thus of the livability in the study area. As shown in Fig. 5, the main difference in PET values between all the scenarios investigated at receptors 1 and 2 occurs between 14:00 and 15:00. Specifically, the scenario B, which represents the current status of the study area, experiences the highest values of PET. Here the maximum differences with the scenario E are 3.36 oC at the receptor 2 and 1.97 oC at the receptor 1. Further, the scenario E performs better than the past scenario A (pre-Xylella conditions) at the receptor 1, while performing the worst at the receptor 2 (Fig. 5A,C).

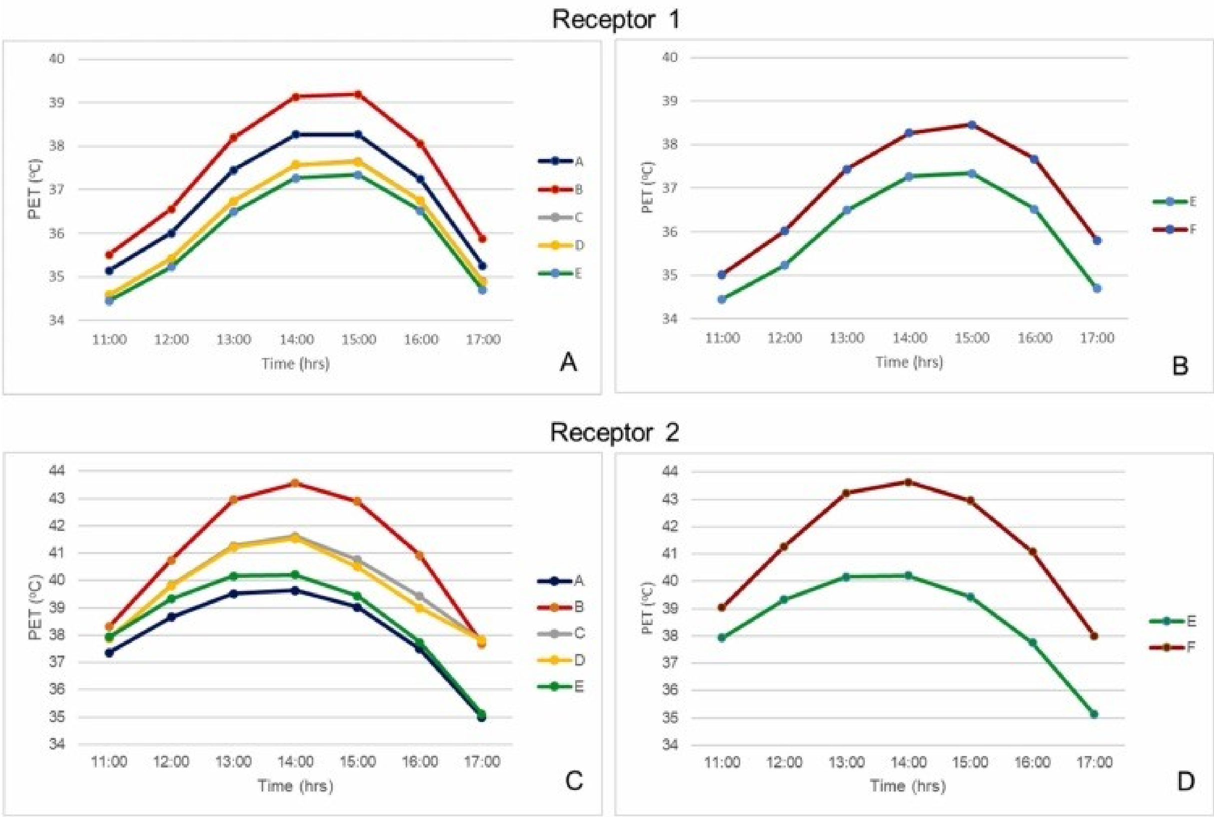

Fig. 5. PET daily time series at the two receptors analysed for the different scenarios (A-E) in the study area. Results refer to ENVI-met simulations with 270º wind direction.

Comparing the scenarios E and F (urban planning considering only lawn vegetation), the human thermal comfort is improved in the scenario E at both receptors. The PET differences are higher (up to 3.5 oC) at the receptor 2 (Fig. 5B,D).

Appling the Wilcoxon paired test to analyse the normality conditions of the data distributions characterized by the small number of data (Kerby et al., 2014), it is possible to note that there exists a significant difference in PET values between scenario E and the other scenarios (Table 2). There are no significant differences between the scenarios C and D where the main difference is in the shape of some buildings.

Table 2. Wilcoxon paired test comparing results at the four receptors for the scenario E vs the other scenarios (W: Wilcoxon test, Z: Normal approx.; M.C. Monte Carlo). Results refer to ENVI-met simulations with 270º wind direction.

Empty Cell		Scenario A	Scenario B	Scenario C	Scenario D	Scenario F
Receptor 1						
	W	28	28	28	28	28
Scenario E	Z	2.366	2.366	2.366	2.366	2.366
	P value	0.0180	0.0180	0.0180	0.0180	0.0180

Empty Cell		Scenario A	Scenario B	Scenario C	Scenario D	Scenario F
	M.C	0.0160	0.0150	0.0155	0.0146	0.0160
Receptor 2						
	W	28	28	27	27	28
	Z	2.366	2.366	1.197	2.197	2.366
Scenario E	P value	0.0180	0.0180	0.0280	0.0280	0.0180
	M.C	0.0150	0.0160	0.0311	0.0308	0.0162

The analysis above has shown maximum differences of PET between 14:00 and 15:00 for different scenarios. As an example, here the analysis is extended to the investigation of the spatial distribution of PET at 14:00 to better show how the scenarios investigated influence outdoor thermal comfort (Fig. 6). In general, the maps show a general reduction of PET in the scenarios C, D, E with respect to the scenarios B and F. It can be noted that in the public area where community garden is introduced (scenario E), PET values decrease to about 40 oC which is considered the limit for human health (Nouri et al., 2018). The trees are useful also to improve the human thermal comfort around the buildings area.

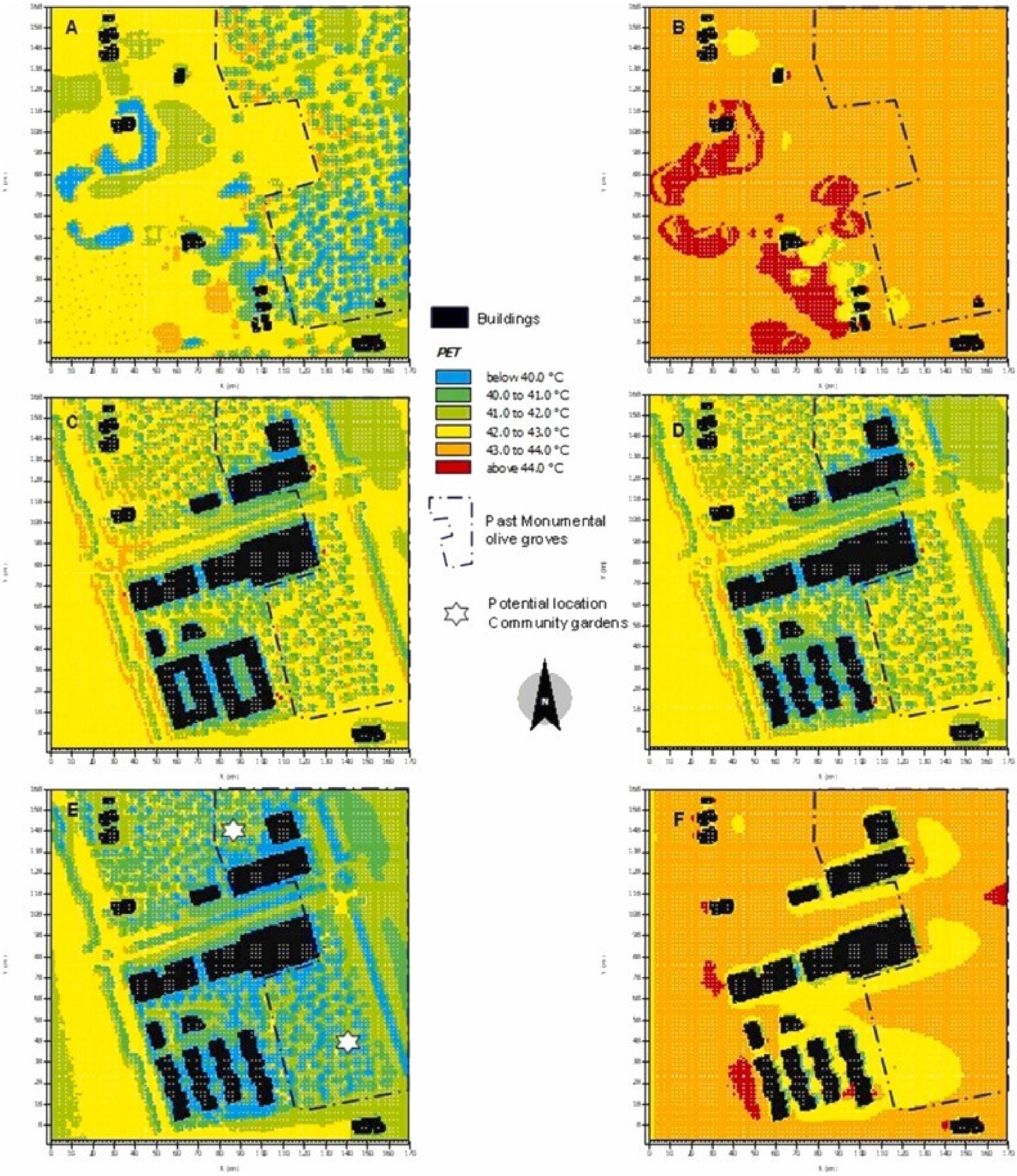

Fig. 6. Spatial distribution of PET at 14:00 for all the scenarios investigated. Results refer to ENVI-met simulations with 270º wind direction.

4.2 225º wind direction

Similar to what was found for the 270º wind direction, the analysis of results obtained for the 225º wind direction shows that the scenario E is the best in terms of improvement of thermal comfort and thus of livability in the study area. As shown in Fig. 7, the main differences in PET values between all the scenarios investigated at the receptors 1 and 2 occur between 14:00 and 15:00.

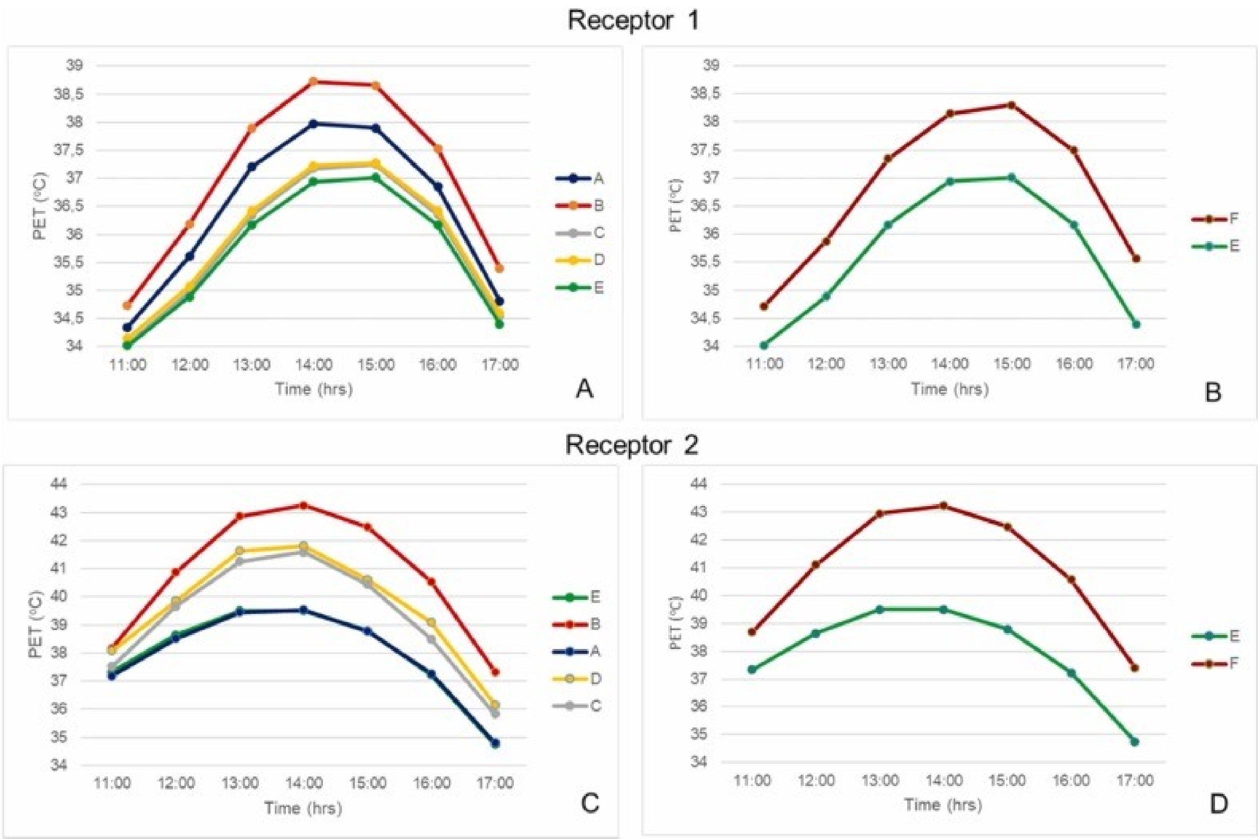

Fig. 7. PET daily time series at the two receptors analysed for the different scenarios (A-E) in the study area. Results refer to ENVI-met simulations with 225º wind direction.

Specifically, the scenario B, which represents the current status of the study area, experiences the highest values of PET. Here the maximum differences with the scenario E are 3.7 oC at the receptor 2 and 1.8 oC at the receptor 1. Further, the scenario E performs better than the past scenario A (pre-Xylella conditions) at the receptor 1, while no significant differences are found at the receptor 2 (Fig. 7A,C).

Comparing the scenarios E and F (urban planning considering only lawn vegetation), the human thermal comfort is improved in the scenario E at both receptors. The PET differences are higher (up to 3.7 oC) at the receptor 2 (Fig. 7B,D).

Appling the Wilcoxon paired test, it is possible to note that there exists a significant difference in PET values between scenario E and the other scenarios, except for the scenario A at the receptor 2 as already estimated from the time series (Table 3). There are no significant differences between the scenarios C and D where the main difference is in some building shapes.

Table 3. Wilcoxon paired test comparing results at the two receptors for the scenario E vs the other scenarios (W: Wilcoxon test, Z: Normal approx.; M.C. Monte Carlo). Results refer to ENVI-met simulations with 225º wind direction.

		Scenario A	Scenario B	Scenario C	Scenario D	Scenario F
Receptor 1						
	W	28	28	28	28	28
	Z	2.366	2.366	2.366	2.366	2.366
Scenario E	P value	0.0180	0.0180	0.0180	0.0180	0.0180
	M.C	0.0150	0.0160	0.0153	0.0153	0.0162
Receptor 2						
	W	19	28	28	28	28
	Z	0.8452	2.366	2.366	2.366	2.366
Scenario E	P value	0.3980	0.0180	0.0180	0.0180	0.0180
	M.C	0.4700	0.0159	0.0154	0.0160	0.0156

As an example, the analysis is extended to the investigation of spatial distribution of PET at 14:00 to better show how the investigated scenarios influence outdoor thermal comfort (Fig. 8). In general, the maps show a general reduction of PET in the scenarios C, D, E to the scenarios B and F. It can be noted that in the public area where community garden is introduced (scenario E), PET values decrease to about 40 oC. The trees are useful also to improve the human thermal comfort around the buildings area.

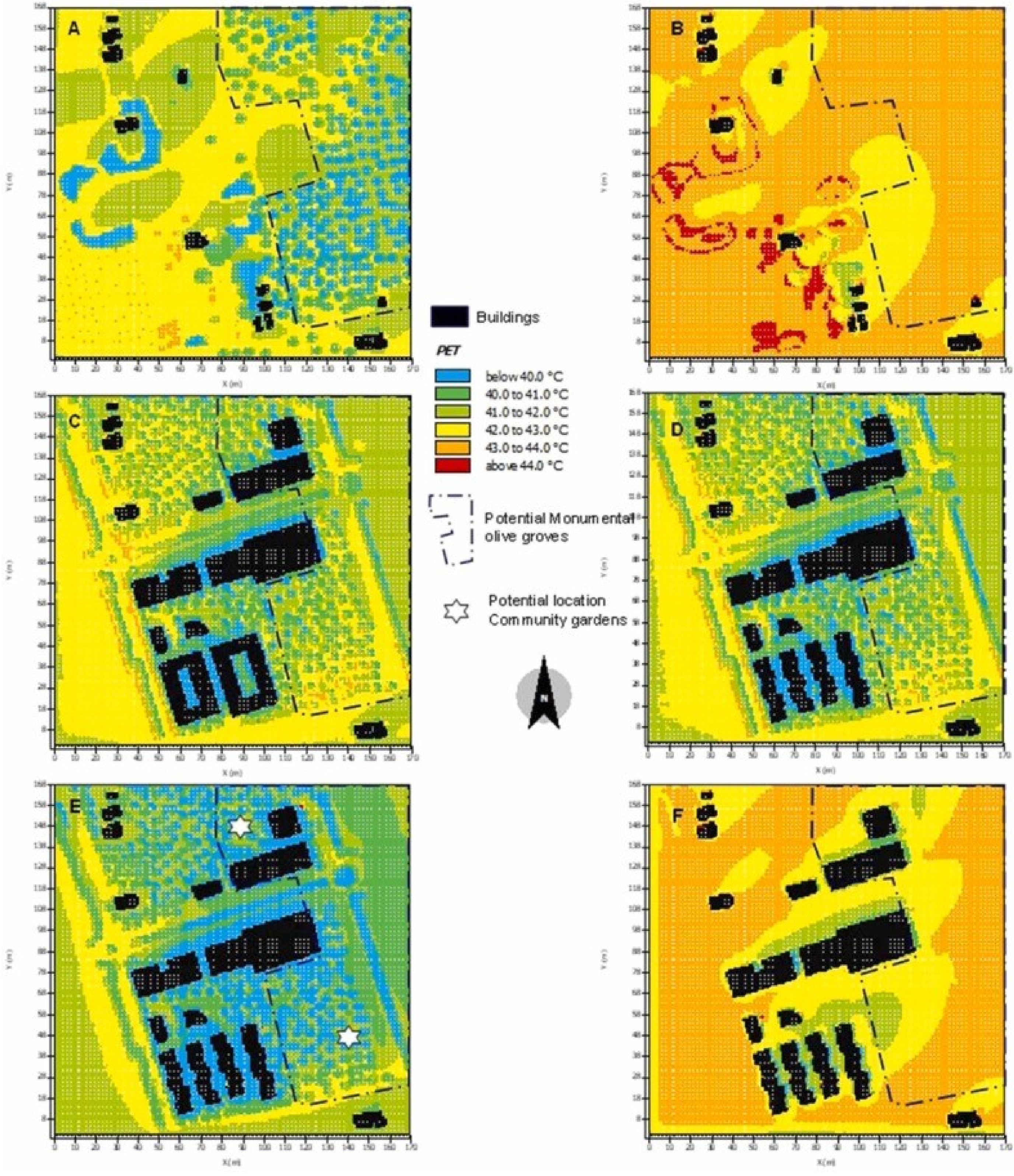

Fig. 8. Spatial distribution of PET at 14:00 for all the scenarios investigated. Results refer to ENVI-met simulations with 225º wind direction.

4.3. Evaluation of a modified scenario E

All the considered UNP scenarios developed here have been built taking into consideration urban planning rules at the municipality level. The analysis above has shown that Scenario E is the best in terms of human thermal comfort improvement with respect to the current status. Here, to explore other solutions which could lead to a further improvement of thermal comfort, another scenario (E-1) is considered. The new scenario is similar to the scenario E but developed by neglecting the urban municipal plan restrictions, while including taller buildings but with low surface area to achieve more volume with less surface area. It is intended to understand if a more flexible municipal plan could help to improve the sustainability (Fig. 9-I).(Table 4)

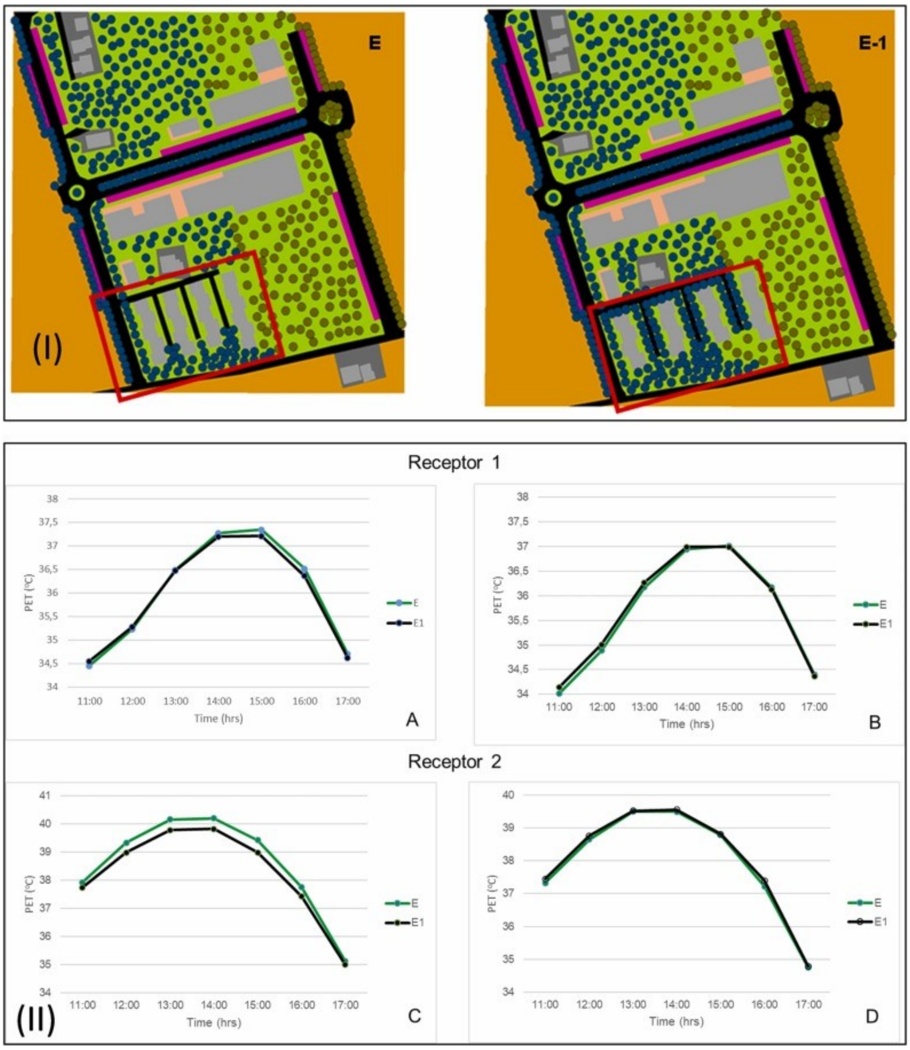

Fig. 9. I) Scenarios E and E-1. The latter is similar to scenario E, but the buildings in the red square are positioned further apart from each other and they are shorter but higher than those in the scenario E. II) PET daily time series at the two receptors analysed for scenarios E and E-1 in the study area. Results refer to ENVI-met simulations with 270° wind direction (A and B) and 225° wind direction (C and D). II shows that, at the two receptors, the scenario E-1 experiences better PET values for the 270° wind direction, whereas the behaviour is the opposite for the 225° wind direction. However, the differences are not significant at the receptor 1 for both wind directions. On the other hand, at the receptor 2, the differences are statistically significant but not large, although the value decreases below 40°C for the 270° wind direction.

Table 4. Wilcoxon paired test comparing results at the two receptors for the scenario E vs the scenario E-1 (W: Wilcoxon test, Z: Normal approx.; M.C. Monte Carlo). Results refer to ENVI-met simulations.

Empty Cell		270o wind direction	225o wind direction
		Scenario E-1	
Receptor 1			
Scenario E	W	21	22
	Z	1.183	1.352
	P value	0.2367	0.1763
	M.C	0.2970	0.2197
Receptor 2			
Scenario E	W	28	28
	Z	2.36	2.36
	P value	0.0180	0.0180
	M.C	0.0156	0.0153

Considering the spatial distribution of PET at 14:00 (Fig. 10), scenario E-1 presents a better situation around buildings, due to larger distances between buildings allowing for a step-up higher presence of trees along the perimeters than scenario E.

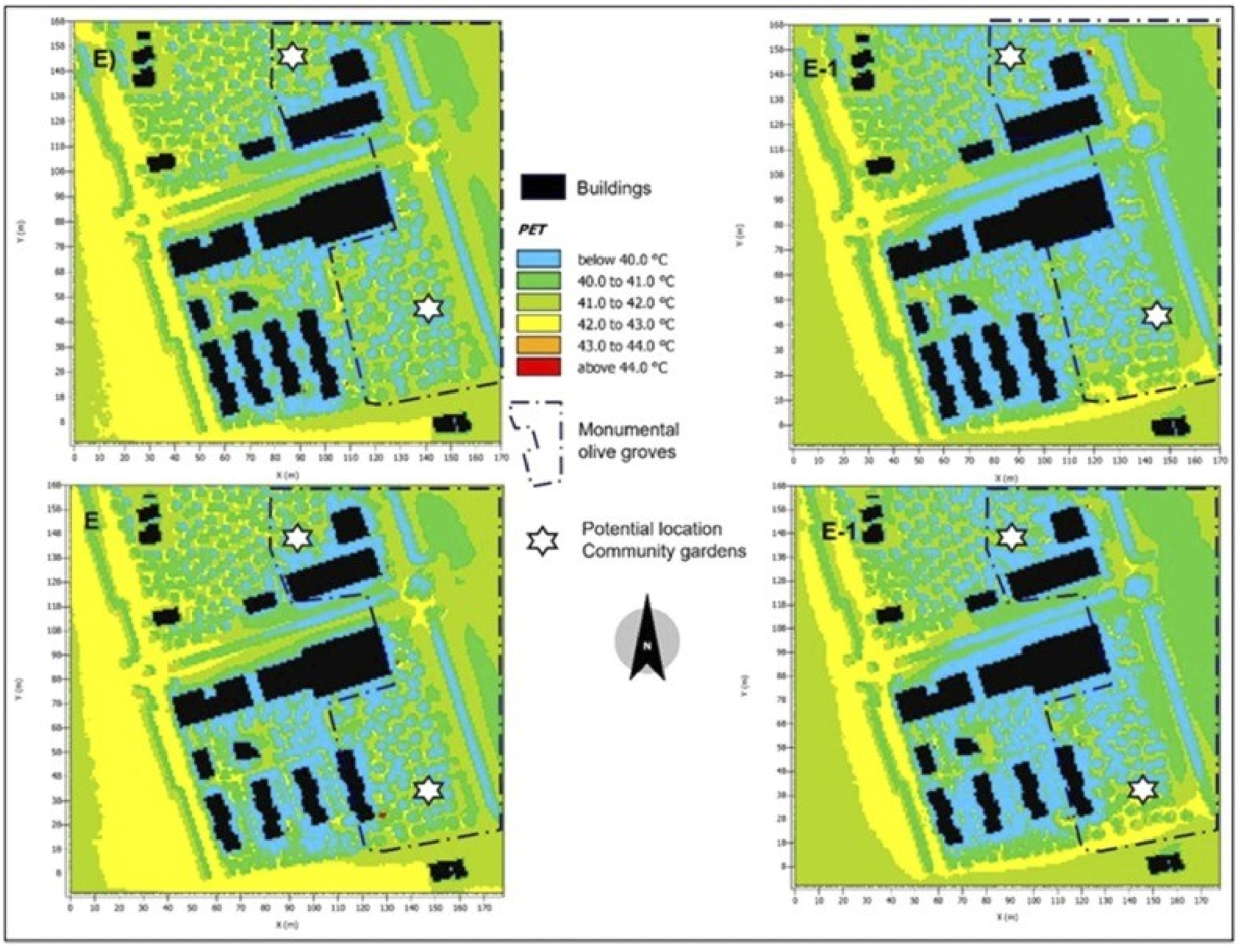

Fig. 10. Spatial distribution of PET at 14:00 for the scenarios E and E-1. Results refer to ENVI-met simulations with 275º wind directions (top) and 225º wind direction (bottom).

5. Discussion

The present study has allowed us to identify the best combination between natural capital and human-derived capital in the developed UNP scenarios. Mainly, during the day when maximum temperatures occur, lower spatially-averaged PET values have been obtained in the scenario E with respect to the current status (scenario B) (Fig. 11). Such scenario could be a good strategy to increase the urban capital considering the social and financial interest in land use of this area focused on the urbanization processes and not on the agricultural utilization. The planned land use and land cover can increase priority ESs and co-benefits linked to cultural and social activities that can be potentially developed for the presence of the agricultural vegetation. Indeed, in the scenario E the urban community garden design with olive trees could be a good strategy to mitigate urban microclimate keeping cultural services linked to the historical presence of this cultivation in the landscape context of the UNP. Of course, it is not possible to restore the monumental olive trees in a short time, such as in the scenario A (past scenario), but with a long-time vision of planning actions, it is possible to think that growing new olive trees following the past tradition could be a useful action to restore the cultural ESs.

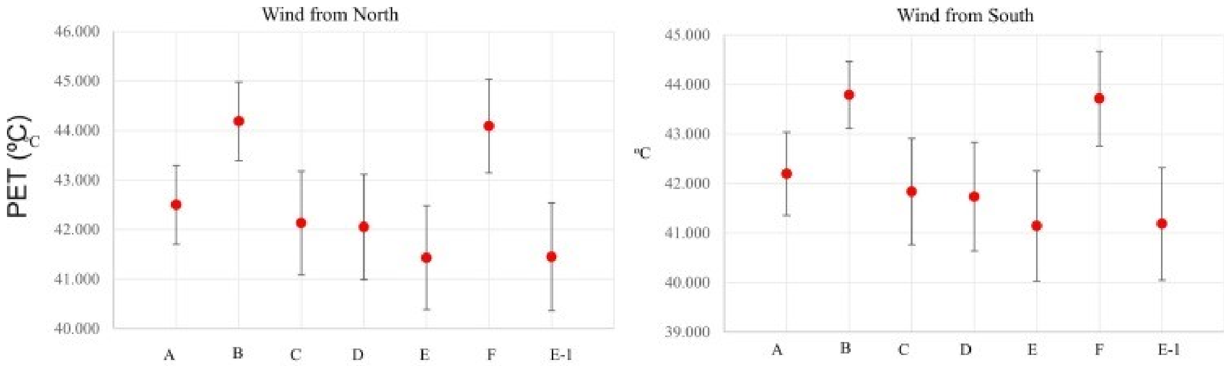

Fig. 11. Spatially averaged PET values obtained at 14:00 for all the UNP scenarios analysed.

The comparison between scenarios E and F (Fig. 8, Fig. 11), the latter presenting the same human-derived capital of the scenario E but different natural capital, characterized by lawn vegetation, has shown high differences in PET values due to the presence of land cover characterized by trees in the scenario E. This result may help planners to quantify the effect of NbS in the UNP and eventually estimate value under a cost-benefit analysis of different solutions proposed. In this study, a cost-benefit analysis has not been carried out, but it is possible to estimate that an initial investment for tree planting (about 240 plants/ha, scenario E) of about 10.000-15.000€/ha, against the 8.000-5.000€/ha for sowing natural lawn (scenario F) (Puglia Region Administration, 2022), may produce a PET difference of about 3.5-4ºC in summertime. Moreover, in many open spaces of the scenario E, PET goes down to 40 oC which can be considered a critical value for strong heat stress (Nouri et al., 2018). Perhaps, this difference in cost is justified by the reductions of human thermal discomfort stress and increase the livability of open spaces for leisure time and social activities during hot periods. Indeed, some scholars showed an increase in respiratory and cardiovascular death with a high PET value and its significant relation to mortality (Nastos and Matzarakis, 2012, Sharafkhani et al., 2018, Dastoorpoor et al., 2021). Therefore, the cost investment of NbS can be useful to reduce the cost impact of urbanization on human capital linked to health expenditure considering the one-day hospital cost for a single person is a minimum 200€/day/person (Gazzetta Ufficiale, 2013). This advantage is even more important in view of climate change which produces an increase in temperature that will amplify the impact on human thermal comfort and human health in the urban area.

Of course, the scenario E has been optimized based on the thermal comfort improvement by changing only the natural capital. Further scenarios should be analysed considering multiple factors such as norms, constraints, but also subjective choices by the designers. Here, with the aim of analysing the impact of human-derived capital, neglecting the municipal planning rules, a new scenario (E-1) with less land use and land cover has been proposed, based on scenario E but with taller residential buildings and a different residential area. The position of buildings in the new scenario E-1 may permit the planting of more intense edge trees around the buildings avoiding possible ecosystem disservices generated by plant roots as in the scenario E (Semeraro et al., 2021a, von Döhren and Haase, 2022) (Fig. 10, Fig. 11). The framework proposed here could represent a cultural leap in the use of the concept of ESs in decision support for sustainability in urban planning, starting from simple assessment and mapping actions to an approach that combines the ability to plan and design NbS to improve UESs with the measurement of them, which are too often developed in isolation.

Developing the UESs, combining urban land use with agricultural land cover, could be a good strategy to reduce the effect of UHI in European cities and reduce the impact on cultural value of the peri-urban area that is characterized by strong interaction from ecological, cultural and social-economic aspects (Fig. 12). We expect that this type of solution can be applied directly to the Mediterranean biogeographical region characterized by similar vegetation and climate conditions of those considered in the investigated area. Further, the framework proposed here can be applied to all biogeographical areas because it provides a general methodology to study the combination of natural capital and human-derived capital in urban planning and the contribution of NbS considering the comparison between scenarios that can be simulated for different climates.

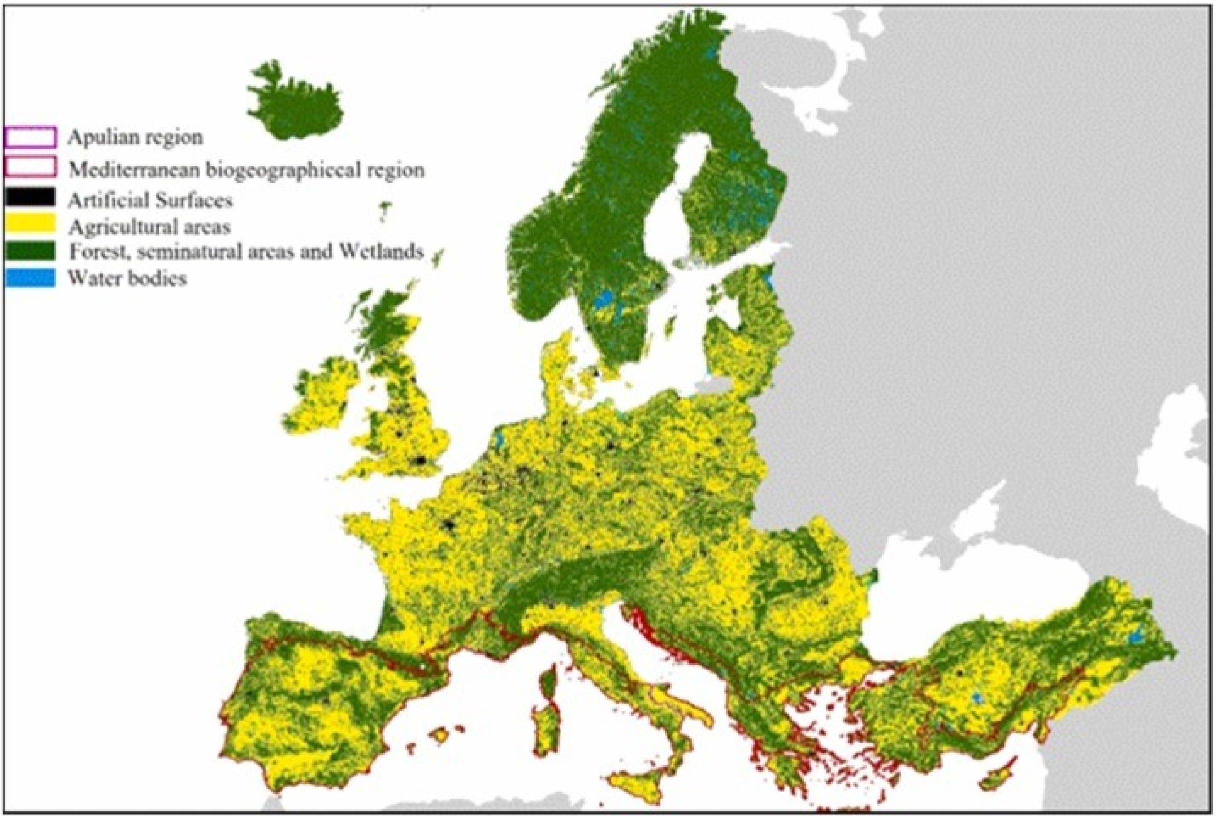

Fig. 12. The border interaction between urban and agricultural areas in the European zone where the framework employed here can be applied and the biogeographical area where a similar application to the Gallipoli area can be performed.

5.1. Limitations and future perspectives

It should be noted that here the human thermal comfort has been an intrinsic choice related to the objective of the UNP to reduce UHI effects and increase the quality of urban spaces. The choice of priority ESs is linked to the context of the analysis (Paramita et al., 2022). Different destinations of land use, for example, agricultural productions can have different ESs priorities. Therefore, the PET has been here considered as a priority index to analyse because the study focuses on microclimate ESs considering the context of the study area and the aim of the UNP. In another case study, the framework (Fig. 2) can be applied using different priority ESs in consideration of the main environmental risk and factors that can influence the human livability.

Further, the choice of the best scenario is limited to the effect of NbS on microclimate only, because in the urban area the vegetation can also influence the air quality, soil permeability and water treatment. Thus, the framework proposed here could be integrated with other priority ESs such as gas and water regulation, to improve the capacity to design NbS and assess urban sustainability and livability.

Finally, the framework could also include the assessment of co-benefits provided by non-priority ESs which can derive from the planned NbS in the different scenarios investigated but which have not been here quantified.

6.Conclusions

A decision-making framework is here proposed starting from an applicative case study to assess urban ecosystem services and promote the best design and planning of NbS at the local scale. The analysis of human thermal comfort using the PET index, chosen here as a surrogate to estimate climate regulation as a priority UES in mitigating UHI, has been carried out using the microclimate model ENVI-met.

Simulations of different UNP scenarios, where different vegetation compositions and configuration (as natural capital) were considered, have been carried out considering two wind directions (225º and 270º), have highlighted that the best UNP scenario in terms of thermal comfort is scenario E, showing low PET values mainly between 14:00 and 15:00. This scenario is structured with NbS characterized by community gardens with the possibility to introduce trees able to enhance human thermal comfort and introduce potential co-benefits such as recreation, cultural and artistic information, science and education, habitation, and tourism facilities linked to agricultural characteristics of trees. Mainly, olive trees as agricultural vegetation for community gardens have been chosen in the scenario considering the landscape context of the study area and the past scenario of the peri-urban area where the UNP will be practically implemented.

An additional scenario (E-1) has been investigated by modifying also the built capital with respect to the scenario E (i.e., with a lower waterproofed surface for building construction and higher building height keeping the same capacity for residential people number), experiencing better PET values. Therefore, in future works, the approach employed here could be used to analyse and resume the best scenarios considering multicriteria aspects such as microclimate aspect, land use consumption and economic cost of the different natural capital and built composition.

Results show that the PET implementation in UNP scenarios can, in this context, be considered a good index that can drive the decision makers. This implies that the application of PET in SEA processes can be implemented to include the ESs in the scenarios analysis and evaluate the effect of NbS such as mitigation actions that are important steps included in the SEA processes.

The application of the framework proposed here, based on the design of NbS and the assessment UES in different scenarios, can allow us to create urban plans with more “accountability”, providing certainty to decision-makers about the proposed transformations are sustainable, contributing to assessing the global targets of the 2030 Agenda at local scale.

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CRediT authorship contribution statement

Conceptualization, T.S.; Methodology, T.S.; Software, T.S. and E.G.; validation, L.D.B., A.L., R.E. and R.B.; formal analysis, T.S. and R.B.; investigation, T.S.; resources, T.S.; data curation, T.S.; writing—original draft preparation, T.S.; writing—review and editing, E.G., L.D.B, A.L., R.E. and R.B.; visualization, T.S.; supervision, L.D.B, A.L. and R.B.; funding T.S.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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