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Adopting Resilience Thinking through Nature-Based Solutions within Urban Planning: A Case Study in the City of València

Gemma García-Blanco, Daniel Navarro and Efren Feliu *

Fundación TECNALIA Research & Innovation, 48160 Derio, Spain; gemma.garcia@tecnalia.com (G.G.-B.); daniel.navarro@tecnalia.com (D.N.)
* Correspondence: efren.feliu@tecnalia.com

Abstract: The paper exposes the experience of València in applying climate-resilient thinking to the current revision of the city's General Urban Development Plan. A semi-quantitative, indicator-based risk assessment of heat stress was carried out on the 23 functional areas of the city sectorized by the Plan, including modeling and spatial analysis exercises. A data model of 18 indicators was built to characterize vulnerability. A thermal stress map was developed using the URbCLim model and a heat index was then calculated using Copernicus hourly data (air temperature, humidity, and wind speed) for the period of January 2008–December 2017 at a spatial resolution of 100 m × 100 m. General recommendations at the city level as well as guidelines for development planning in the functional areas at risk are provided, with specifications for the deployment of nature-based solutions as adaptation measures. From a planning perspective, the study positively informs the General Urban Development Plan, the City Green and Biodiversity Plan, and contributes to City Urban Strategy 2030 and City Missions 2030 for climate adaptation and neutrality. Applying the same approach to other climate change-related hazards (i.e., water scarcity, pluvial flooding, sea level rise) will allow better informed decisions towards resilient urban planning.

Keywords: resilience; climate change; risk; adaptative planning; nature-based solutions

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1. Introduction

In a scenario of population growth and usually limited municipal budgets, cities must face increasingly complex challenges, such as the management of land, waste, and energy, assurance of water quality and rainwater management, reduction of air, soil, and noise pollution, mobility management, creation of economic opportunities, maintenance and increase of biodiversity, food security, health and well-being, a progressively more inclusive, fair, and equitable society, as well as the more pressing need to fight and adapt to the effects of climate change [1].

The Intergovernmental Panel on Climate Change (IPCC), already in its fifth iteration and now with its sixth evaluation report, reaffirms climate change as a verifiable reality that entails a progressive change in climate variables as well as an increase in the frequency and severity of extreme events (i.e., floods, heat waves, storms). It also concludes that, even if there was the economic and political will to immediately stop all greenhouse gas (GHG) emissions that are causing the increase in global temperature and pollution, the damages to the functioning of the climate that generates the impacts already considered is, in many cases, irreversible and irreparable, such as the melting of the polar ice caps and the consequent sea level rise [2,3].

On the other hand, from a disaster risk management perspective, cities have a leading role to play in managing the risks [4] associated with climate change, such as those due to extreme temperatures. In this sense, the Sendai Framework for Disaster Risk Management [5] of the United Nations promotes the adoption of measures to limit exposure, reduce vulnerability, increase capacity, and attenuate hazards in order to reduce existing risks and prevent new risks.

Mitigation, understood as human intervention to reduce emission sources or improve GHG sinks, is therefore essential, since more than 40% of total GHGs are emitted by human activities [2], but insufficient. Adaptation, as the process of adjusting our socio-ecological systems to the current or expected climate and its effects, becomes imperative [1,6].

Urban areas can be understood as complex socio-ecological systems that are directly and/or indirectly co-responsible for global change through their contribution to GHG emissions and, at the same time, receptors of the usually adverse climate impacts [7]. Currently, the share of the urban population in the world's population has reached 56%, which is expected to increase to 9.7 billion by 2050, with 68% of inhabitants living in urban areas [8]. Despite the fact that estimates of global urban land stated in various sources vary widely from less than 1% to 3%, mainly due to different definitions of urban land [9], urbanization processes affect the sustainable use of natural resources and put important pressure on ecosystems. Moreover, cities are supposed to be responsible for most of the emissions. The World Resources Institute Global identified greenhouse gas emissions by sector in 2016 as follows: energy use in buildings: 17.5% (commercial: 6.6%, residential: 10.9%); transport: 16.2%; energy use in industry: 24.2%; agriculture, forestry, and land use: 18.4%; waste disposal: 3.2%; and industry: 5.2% [10].

The artificialization process, motorized mobility, energy demand, and loss of soil permeability cause important changes in the water cycle, and thermal stress derived from the intensification of the urban heat island effect may also cause environmental, economic, and social damages. These damages include impacts on health conditions, especially to elder generations [11], harm to housing and infrastructure, loss of business or loss of productivity, and increased household and public service energy demand, among others. Given this situation, despite essential efforts at the global level with large-scale international agreements, certain decisions and actions can and should be conducted at the local level.

In this context, urban planning and management can be seen as a powerful instruments through which climate action could be effectively integrated from both mitigation and adaptation perspectives, combining coping, adaptive, and transformative capacities to build more resilient territorial and city models [1,7].

Depending on the administrative structure and the distribution of powers and responsibilities, many local authorities have robust resources and capacity for climate action, especially relevant from the perspective of adaptation, through the articulation of local policies such as urban planning, drinking water supplies, sanitation networks and wastewater treatment, the management of roads and public spaces, environmental protection, and public health [1,12].

In this context, it is worth noting that the European Strategy for Adaptation to Climate Change 2021 [13], like the previous 2013 strategy, recognizes spatial and urban planning as the main disciplines through which climate action should be implemented due to their ability to coordinate sectoral policies and land use decisions. Additionally, in the same direction, the European Commission's proposal for the first European Climate Law aims to turn into law the goal set out in the European Green Deal: that the European economy and society become climate neutral by 2050 [14]. Spatial and urban planning have a relevant role to play in achieving this goal.

In Spain, the potential of spatial and urban planning to address climate change was recognized at the state level by Law 7/2021 on 20 May, entitled the Climate Change and Energy Transition Law [15]. In its fourth and final provision, the law modifies the consolidated text of the Land and Urban Rehabilitation Law, approved by Royal Legislative Decree 7/2015 on 30 October, incorporating the need to consider the risks arising from climate change in land use planning [16]. Although it is too soon to really evaluate the impact of this modification of the Land and Urban Rehabilitation Law, it is expected to be a remarkable catalyst towards more resilient planning in the Spanish context.

The renaturing of cities through increased emphasis on the use of nature-based solutions (NbS) has been gaining significance in the climate change context in recent years, since it offers urban areas the opportunity to deliver multiple environmental, social, and socio-economic benefits with blue and green non-regret interventions [7].

NbS are conceived as interventions that use natural ecosystems or incorporate elements inspired by nature and its processes, such as green roofs and facades or natural lamination rafts, among others, to help society cope with climate change. This approach values multifunctionality and the environmental, social, and economic co-benefits of NbS being able to simultaneously respond to different urban challenges, as well as with good cost-effectiveness ratios [7,17–20].

To successfully deploy NbS to address climate change, it is important to have a good understanding of the existing environmental conditions and evaluate the spatially explicit distribution of risks and vulnerabilities within the city in order to identify the areas in need of priority action [1,21–24].

1.1. Context and Description of the Case Study

València is the capital city of the Autonomous Community of València. The city is located on the eastern Mediterranean coast of Spain and is the third largest city in the country demographically and economically. In 2021, the population was 800,180 inhabitants, which amounted to 1,581,057 inhabitants if its metropolitan area was included, thus being the third most populated city in Spain after Madrid and Barcelona. Its climate is characterized by hot summers and low rainfall, with episodes of heavy rain. Climate change predictions suggest that higher temperatures, less precipitation, and more extreme weather episodes associated with rainfall and heat wave events are likely.

The vision and development principles that guide the municipal public policies and the plans and strategies developed by the city of València are those of a 21st century city: healthy, free of emissions and pollution, green and natural, participatory, supportive, and inclusive, tailored to people. This vision and these principles emerge in the city's Urban Agenda 2030 [25], for which the design, proposed by the municipal government, followed a co-participatory process in which almost all municipal departments and the representatives of the civil society were actively involved. Within Urban Agenda 2030, València also launched València Climate Missions 2030, which proposed four axes—healthy city, sustainable city, shared city, and entrepreneurial city—to develop strategic lines that cover the objectives of sustainable development, with an important focus on addressing climate change and energy transition [26].

At the regional level, València has a mature territorial and urban planning system that is specified in Law 5/2012, entitled Territorial Planning, Urbanism and Landscape of the Valencian Community. This law describes the articulation of multi-scale planning instruments, including the Territorial Strategy of the Valencian Community, Territorial Action Plans, the General Urban Development Plan, and other multisectoral strategic territorial actions. The Territorial Strategy of the Autonomous Community of València also includes specific formulas for territorial governance, which allow administrative and public–private cooperation and coordination to develop dynamic projects in the territory, with a complementary distribution of powers between public administrations at regional, provincial, and local levels. Law 6/2022 was approved on 5 December 2022, entitled Climate Change and Ecological Transition of the Valencian Community, which was considered a very relevant step towards resilience in the region [27].

From the early 2000s, the city of València has joined a series of climate action initiatives, starting with the Covenant of Mayors signed in 2009, with the commitment to reduce GHG emissions by 20% by 2020 through the approval of a Sustainable Energy Action Plan (SEAP) 2010, followed by the Strategy Against Climate Change València 2020 in 2011. The integration of two previous plans, the Environmental Action Plan—which formed part of the Local Agenda 21 process—and the SEAP itself, led to new commitments in 2014 and the Covenant of Mayors for Climate and Energy 2015. In 2017, the València 2050 Plan for Adaptation to Climate Change was published in collaboration with the different areas of the City Council involved. In April 2019, the municipal plenary session approved the

Sustainable Energy and Climate Action Plan (SECAP). In September 2019, the municipal plenary session approved the Climate Emergency Declaration. In August 2020, the City's Energy Transition Board, made up of representatives from all social sectors of València (NGOs, academia, public, and private), was created to develop a participatory roadmap towards decarbonization. In September 2020, the municipal plenary session approved the València 2030 Strategic Framework Agreement, an urban agenda tool aimed at accelerating the transition towards a more sustainable, healthier, more shared, and more prosperous city. In February 2021, the municipal plenary session approved the 'València neutral city' mission aimed at achieving climate neutrality in three city neighborhoods by 2030. In March 2021, the municipal plenary session approved adherence to the Green City Accord, a commitment by European cities to the conservation of the environment, agreeing to take measures to improve air quality, the use of water, and the conservation of urban biodiversity, moving towards a circular economy, circular urban planning applying retrofitting approaches and multifunctionality of spaces, and reduction of noise pollution, as objectives to be met by 2030.

1.2. Climate Change Related Hazards in València

The most relevant climate-related hazard in València is heat stress, with an extraordinary impact on human health and well-being that is foreseen to worsen in the coming decades due to climate change. The historical data collected for average temperature in València in the period 1951–2022 showed an increasing trend (Figure 1). The period 1994–2021 was among the warmest years on record for surface temperature (except 2010).

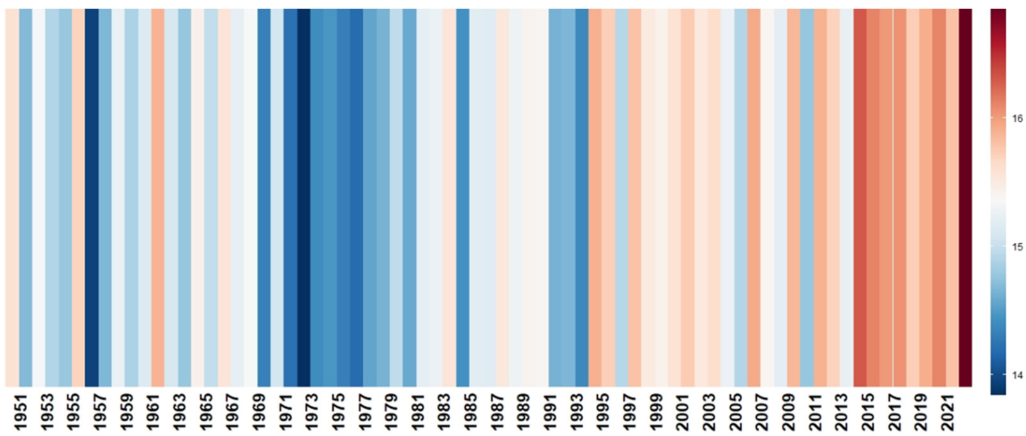

Figure 1. Representation of the average temperature of the València observatory in the period 1951–2022 through "warming stripes." Source: Spanish Meteorological Agency AEMET Comunitat Valenciana.

The following figures show temperature projections (based on Euro-CORDEX) for the future climate change scenarios RCP 4.5 and 8.5 as well as observational data. The evaluation of all of the indicators analyzed in relation to temperature indicated a positive trend. Notably, this increase in temperatures was even greater for the RCP 4.5 climate scenario from 2040 onwards.

As shown in Figure 2, by the end of the century, the maximum annual temperature may rise between 1.8 and 3.2 °C, with respect to the reference period (RCP 4.5 and 8.5, respectively). In addition, climate models show that this increase would be greater for annual minimum temperatures rising between 2.1 and 4.0 °C.

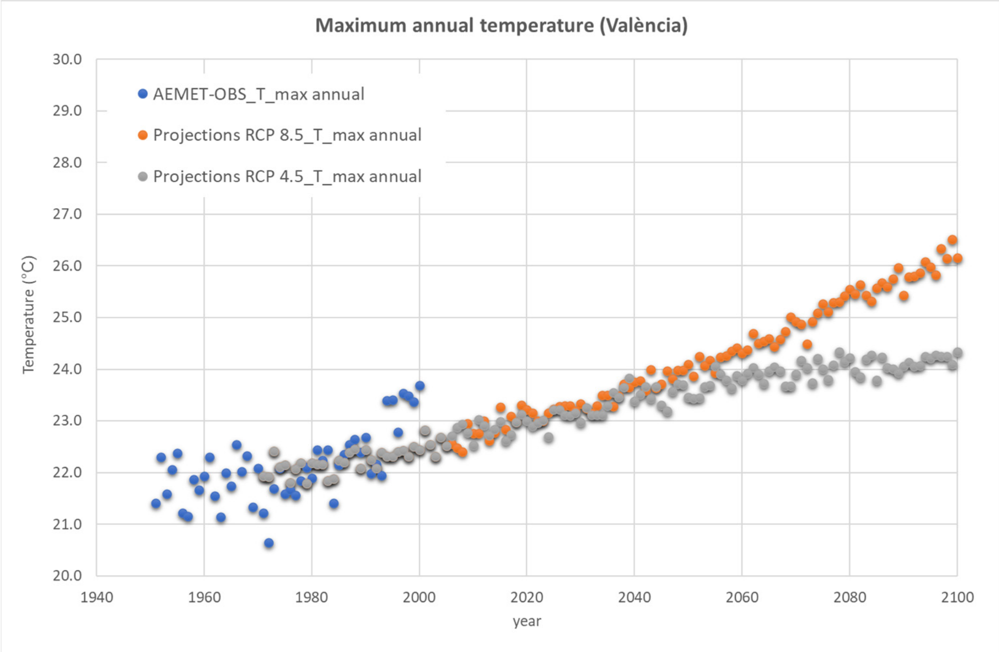

Figure 2. Maximum annual temperature in València. Reference period 1971–2000. Source: Processed from data from Adaptecca's climate scenario viewer.

In addition, climate models show a decrease in the number of days below freezing (Tmin < 0 °C) that, together with the decrease in duration and frequency, predict the disappearance of cold waves in the RCP 8.5 scenario for the last half of the XXI century.

Regarding temperature-related extreme events associated with thermal comfort and the well-being of the population, projections show an increase in the duration of heat waves as well as an increase in the number of warm nights (number of days in a period in which the minimum temperature exceeds the 90th percentile of a reference climatic period), which may be between 2 and 3 times more frequent by the end of the present century.

On the other hand, in the last decade there has been a slight increase in the duration and frequency of heat waves (Figure 3). This increase in the maximum duration of heat waves may mean an average duration of heat waves of around 17 days between the years 2010 and 2039, i.e., double the average duration of the historical period 1971–1980.

1.3. The Revision of the General Urban Development Plan of València: An Innovative Approach

In 2018, the València city council started revising the General Urban Development Plan using an innovative approach, which was awarded a prestigious national award by the Spanish Training and Urban Development Foundation.

The revision of the General Development Urban Plan applied an innovative approach with a strong spatial component that materialized in the delimitation of 23 functional planning areas, as described in the Special Plan of Urban Quality Guidelines of València [28] (Figure 4).

The 23 functional areas resulted from an analysis of historical development, physical support, as well as administrative division of the city. However, some areas, specifically the outermost areas, exceeded the administrative boundaries of the municipality, so existing interactions with the adjoining municipalities of Mislata and Xirivella should be studied.

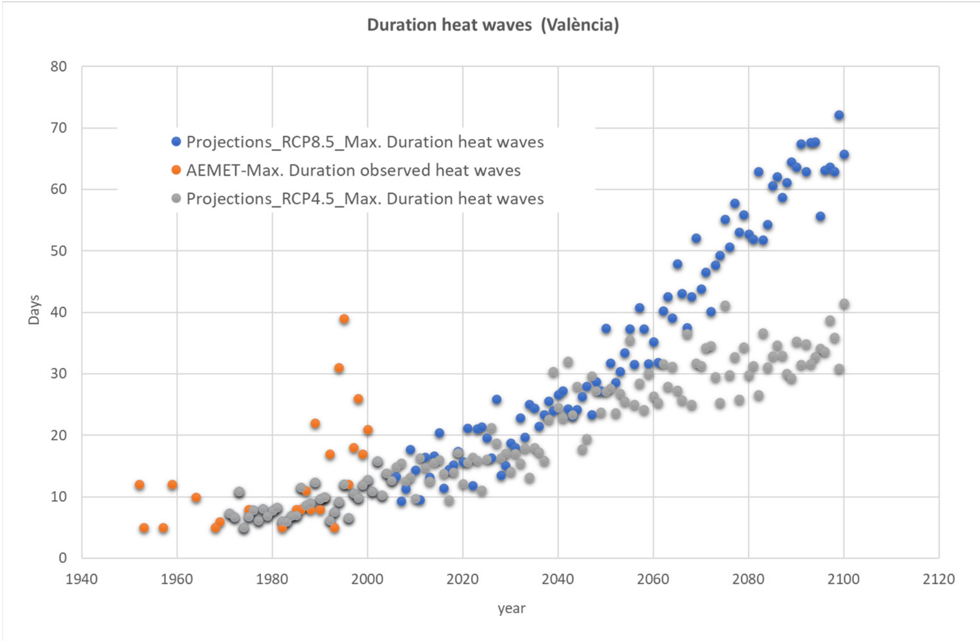

Figure 3. Maximum duration of heat waves in València. Reference period 1971–2000. Source: Proceeding from data from Adaptecca's climate scenario viewer.

Functional Area	Surface m^2	Inhab. (2016)
1	1,484,186.29	27,124
2	1,393,192.84	41,785
3	158,617.21	49,026
4	1,831,921.81	28,315
5	1,751,363.08	50,530
6	1,472,527.39	26,588
7	2,556,056.51	89,310
8	2,119,971.66	38,324
9	1,753,855.64	38,058
10	744,827.99	7.557
11	1,794,430.92	46,252
12	938,151.22	21,769
13	1,078,913.56	38,654
14	2,027,188.79	56,276
15	583,105.10	25,909
16	1,915,298.21	41,425
17	1,499,090.22	50,453
18	1,220,384.23	32,962
19	237,839.77	2.933
20	934,877.24	12,682
21	398,092.98	10,012
22	422,533.47	8.558
23	179,014.67	5.066

Figure 4. The 23 functional areas that sectorize the city of València for urban planning purposes in the revision of the General Plan for Urban Planning. Source: Adapted from the Special Plan of Urban Quality Guidelines of València [28].

The functional areas were characterized based on indicators of a physical, urban, social, and environmental nature (Figure 5), which were organized around thematic fields (land, built heritage, social identity and culture, facilities, public space, housing, and mobility) in which urban planning has the capacity to act. Under comparable parameters, functional imbalances could be found and corrected between functional areas, improving accessibility to services on foot and optimizing the land, thus responding to the guidelines of sustainability, efficiency, and satisfaction of citizen demand. The two fundamental parameters on which the functional balance of residential areas was built were: (a) the availability of land for pedestrians, and (b) the accessibility to public services.

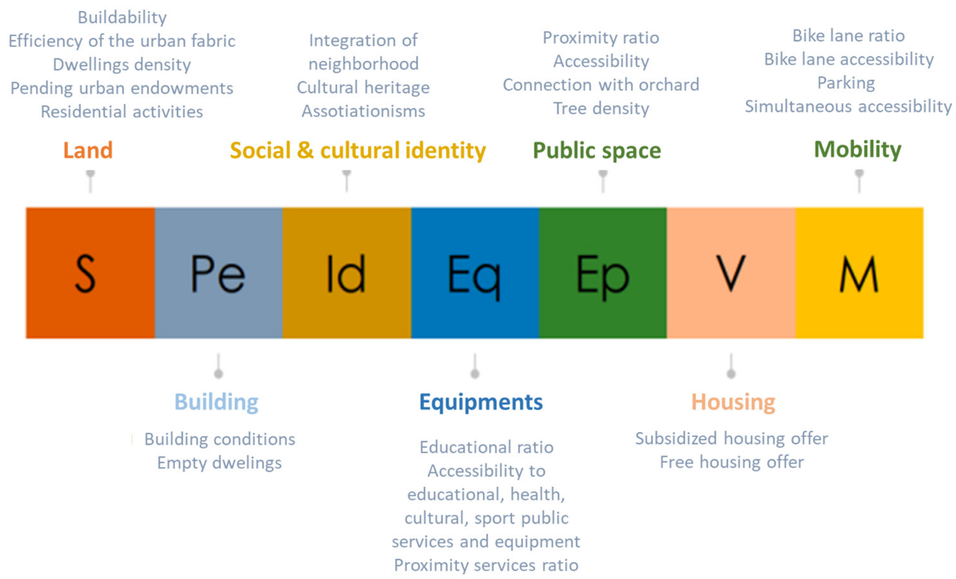

Figure 5. System of indicators used to characterize the functional areas in the revision of the General Urban Development Plan. Source: Special Plan of Urban Quality Guidelines of València [28].

This functional delimitation generated a new structure of the city and increased the degree of influence of its neighborhoods, which acquired the category of centrality of each functional area and was the starting point of the green infrastructure of the area and around which superblocks would be available. Only a few neighborhoods, such as Mestalla (distributed between areas 6, 7, and 9), Grao, and San Llorens, exceeded the scope of the functional areas. In the case of Mestalla, the barriers of Avenida de Aragón and Avenida del Puerto have historically divided this neighborhood, as they are rail traffic axes and provide access to the port.

The characterization of the functional areas was then completed with an analysis of urban green infrastructure accessibility and connectivity, and on this basis, detailed planning guidelines were drawn up for each functional area.

Through the functional areas, the entire city was connected at two scales: that of road traffic, supported by the main infrastructure of the city, and that of the pedestrian, based on the urban green infrastructure. Thus, the city was viewed as a network that connects public services and neighborhoods.

In these functional areas, the concept of neighborhood was recovered as a space in which the interventions for the improvement of urban quality would be most effectively implemented.

The innovative approach and planning process described above were used as a basis for the applied research work described in this paper in the following sections.

The revision of the General Urban Development Plan represented an opportunity to strengthen the consideration of climate risks, thus allowing better informed decision-making with regards to urban planning and risk management and the deployment of green and blue infrastructures and NbS as climate action measures.

The operationalization of climate action in the urban planning of València anticipated the requirements of climate change laws at the state and regional levels reinforced in 2021 by the institutional Climate Emergency Declaration and the commitments made by the local government.

2. Materials and Methods

2.1. Study Design and Data Sources

The incorporation of the climate change perspective into the revision of the General Urban Development Plan of the city of València constituted a step forward in the city's pathway towards climate action and resilience.

In this context, the Plan stands out as one of the pioneer formal planning instruments in Spain, applying spatially explicit vulnerability and risk assessment in the planning process. The novelty of the Plan relies on the fact that the characterization of functional areas was complemented with an indicator-based risk assessment, which allowed the prioritization of areas with the most significant risk. For those functional areas at risk, guidelines and recommendations for detailed planning were defined, promoting NbS as adaptation measures.

The vulnerability and risk assessment was carried out for thermal stress and its effect on the population, as it is one of the priority climate hazards in Mediterranean cities, and València is not an exception [29,30]. Thermal stress on the population was identified in the city's Strategic Agenda 2030 as well as Missions València 2030 [25].

The analytical framework for the evaluation of vulnerability and risk was that suggested in the "Guide for the elaboration of local plans for adaptation to climate change in Spain" [29] (Figure 6), which was based on the approach proposed in the IPCC's Fifth Assessment Report on Impacts, Adaptation and Vulnerability [2].

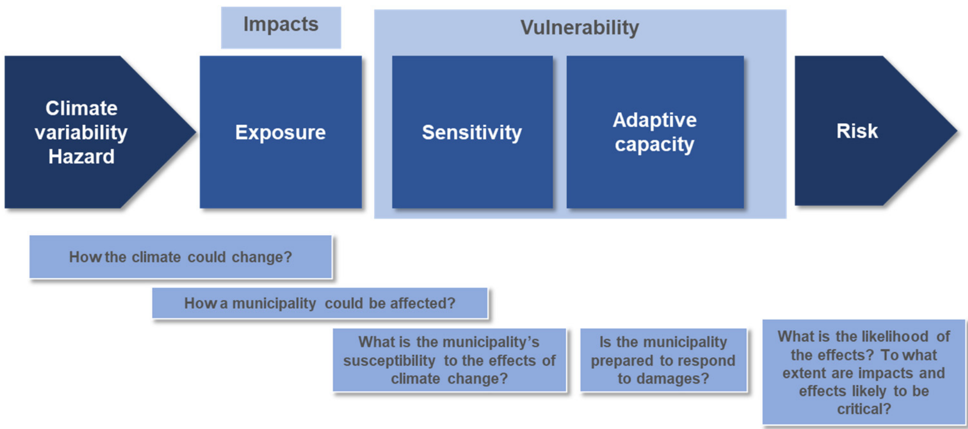

Figure 6. Process of adaptation to climate change at a local scale. Guide for the preparation of local plans for adaptation to climate change in Spain. Source: [2,31].

2.2. Procedures

In this study, the climate hazard was characterized by means of the heat index indicator [32], which was derived from multiple regression analysis and considered the impact of air temperature and relative humidity on human comfort (Equation (1)) [30,32,33]. For this, data provided by the urban climate model UrbClim [34] based on the Copernicus EU program were taken as a reference, with a spatial resolution of 100 m × 100 m and an hourly temporal resolution for the period between January 2008 and December 2017. The day with the highest heat index score within the period was selected as a representative day of the future climate in a climate change scenario [33].

$$\begin{aligned} ST\_c = \; & -8.78469476 + 1.61139411\ T + 2.338548839\ HR - 0.14611605\ T\ HR \\ & -0.012308094\ T2 - 0.016424828\ HR2 + 0.002211732\ T2\ R \\ & +0.00072546\ T\ HR2 - 0.000003582\ T2\ HR2 \end{aligned} \tag{1}$$

As already stated, the evaluation of the risk due to thermal stress on the population used an indicator-based approach (Table 1). A semi-quantitative, indicator-based risk assessment was applied. For each risk component, a series of indicators was selected.

Table 1. List of indicators used in the vulnerability and risk assessment of functional areas for thermal stress on human population. HZ = Hazard; EX = Exposure; VU = Vulnerability; SE = Sensitivity; AC: Adaptative Capacity. Source: Own elaboration.

Component	Dimension	Type	Indicator	Definition
HZ			Heat index	Heat index
EX		Population	Total population	Number of inhabitants per functional area
VU	SE	Land	Buildability	Building coefficient per functional area
VU	SE	Land	Efficiency of the urban fabric	Compacity: building volume by the total surface of the functional area
VU	SE	Population	Population > 65 years old	% of inhabitants > 65 years old in the functional area
VU	SE	Population	Population < 15 years old	% of inhabitants < 15 years old in the functional area
VU	SE	Public space	Artificialized areas	% of impervious land by the total surface of the functional area
VU	SE	Housing	Old residential buildings	% of residential buildings > 50 years (reference year 2020)
VU	AC	Social and cultural identity	Associationism	Existing associations in the functional area
VU	AC	Public services/equipment	Accessibility to health centers	Coverage by radius of distance from health centers
VU	AC	Public services/equipment	Proximity to public facility ratio	Area of local public facilities per inhabitant
VU	AC	Public services/equipment	Global ratio of public facilities	Global area of public facilities per inhabitant
VU	AC	Public space	Proximity to free spaces ratio	Area of free spaces in proximity per inhabitant (gardens)
VU	AC	Public space	Proximity to free spaces ratio	Global area of free spaces per inhabitant (parks, boulevards, and gardens)
VU	AC	Public space	Simultaneous accessibility to free spaces	Circles of coverage by radius of distance (simultaneous accessibility to several types of free spaces)
VU	AC	Public space	Connectivity to the orchard	Percentage of land covered by the areas of influence of the orchards and pedestrian routes
VU	AC	Public space	Density of trees	Number of trees per road surface (urban comfort)
VU	AC	Mobility	Bike lane ratio	Linear meters of bike lanes by length of urban road
VU	AC	Social well-being	Household income	Average household income per functional area calculated from the average data in 2017 assigned to buildings.
VU	AC	Public spaces	Public fountains	Number of fountains in each functional area per hectare

Risk was understood, following the IPPC approach, as the result of the combination of hazard, exposure, and vulnerability, the latter being divided in turn into sensitivity and adaptative capacity [35].

The exposure was analyzed using the indicator of total population exposed to thermal stress in the functional areas of the city [36].

For the assessment of vulnerability, a series of indicators of sensitivity and adaptative capacity was defined [37].

In the first step, the system of indicators used for the characterization of the functional areas for the General Urban Development Plan (Figure 5) was analyzed to determine which ones could be used to estimate the sensitivity and adaptative capacity to heat stress under analysis.

Subsequently, a database was structured with the selected list of indicators and completed with additional indicators and variables of a social, economic, environmental, and physical nature, selecting the information available in the Open Data portal of the city of València and in the Spatial Data Infrastructure of the city of València.

Once the database was structured and completed with the indicators' values, the approach by Tapia et al. [37] was used for the vulnerability assessment. A series of treatments and statistical tests was undertaken (i.e., normalization, standardization, and rescaling) using R data analysis software. These statistical treatments were needed to generate the respective aggregated indexes of sensitivity and adaptative capacity, and later, by the aggregation of these, to obtain the aggregated vulnerability index of each functional area.

A weighting process was applied to obtain the aggregated indexes of sensitivity and adaptive capacity by assigning different weights to the respective individual indicators. These weights were obtained dynamically using statistical methods (principal components analysis and factor analysis, mainly) to eliminate any potential redundancy in the data used.

Once the weights were generated, the last step was aggregating the different indicators in the sensitivity and adaptative capacity indexes of each functional area. As a form of aggregation, weighted geometric aggregation (multiplicative aggregation) was used instead of weighted arithmetic aggregation (additive aggregation) [38]. In this way, specific aggregated indexes were finally obtained for each functional area. This allowed comparative analysis among the functional areas, identifying which areas had the highest relative vulnerability, thus providing additional information in order to propose local actions aimed at reducing their sensitivity or enhancing their adaptative capacity to climate change.

Finally, the risk was obtained by combining the hazard, exposure, and vulnerability using an equally weighted geometric mean. That is, multiplying these components with a weight of one-third for each of them.

Based on the results of the risk assessment, guidelines and recommendations were then drawn up at two planning levels: (a) structural planning at the city level aimed at refreshing the General Urban Development Plan, and (b) development planning in the functional areas in which significant risk was observed, with specific proposals to reinforce the deployment of NbS as adaptation measures.

Figure 7 shows the sequence of analysis for the incorporation of NbS as adaptation measures in the urban planning of València.

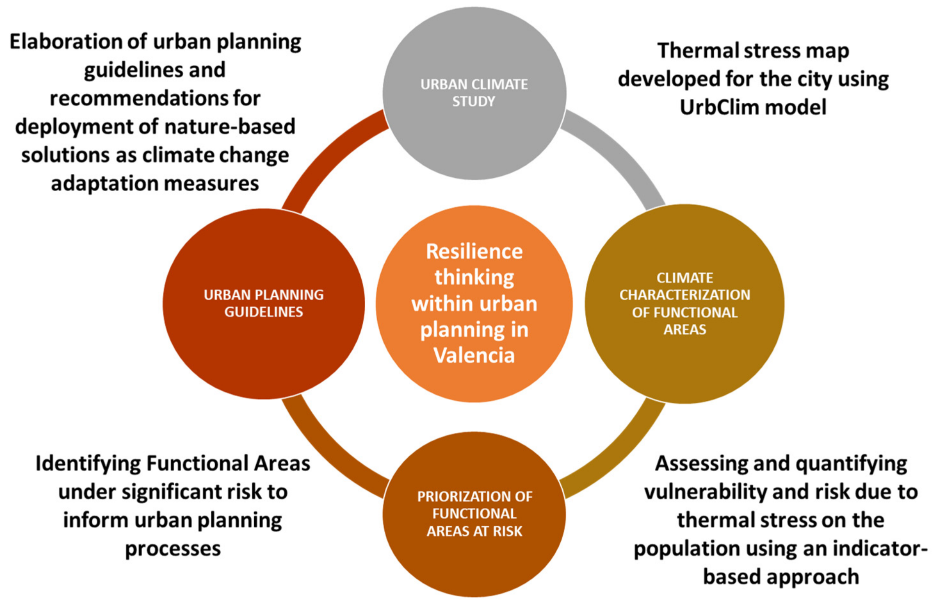

Figure 7. Logical sequence for the consideration of NbS as adaptation measures in the urban planning of València. Source: Own elaboration.

3. Results

After calculating the wind chill index for the entire modeled period, the evolution of the heat index was analyzed and the day with the maximum wind chill value, 27 August 2010, was selected (Figure 8).

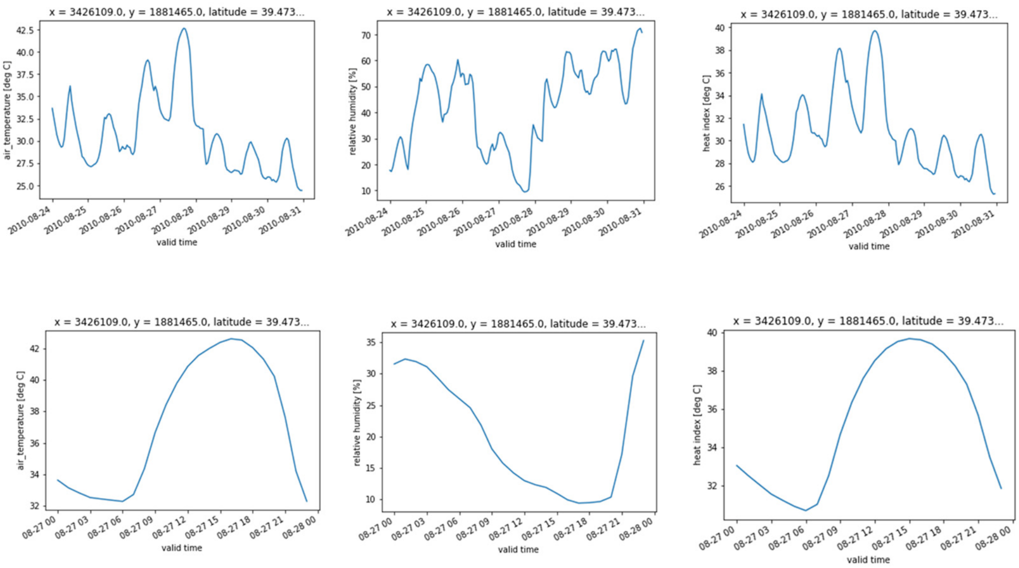

Figure 8. Thermal stress index in València. Source: Own elaboration.

The spatial distribution of the thermal stress is shown in Figure 9. The map revealed that the heat index values obtained for most of the city corresponded to extreme precaution, only 1 °C away from entering the danger zone according to the European Environment Agency and the National Oceanic and Atmospheric Administration rankings.

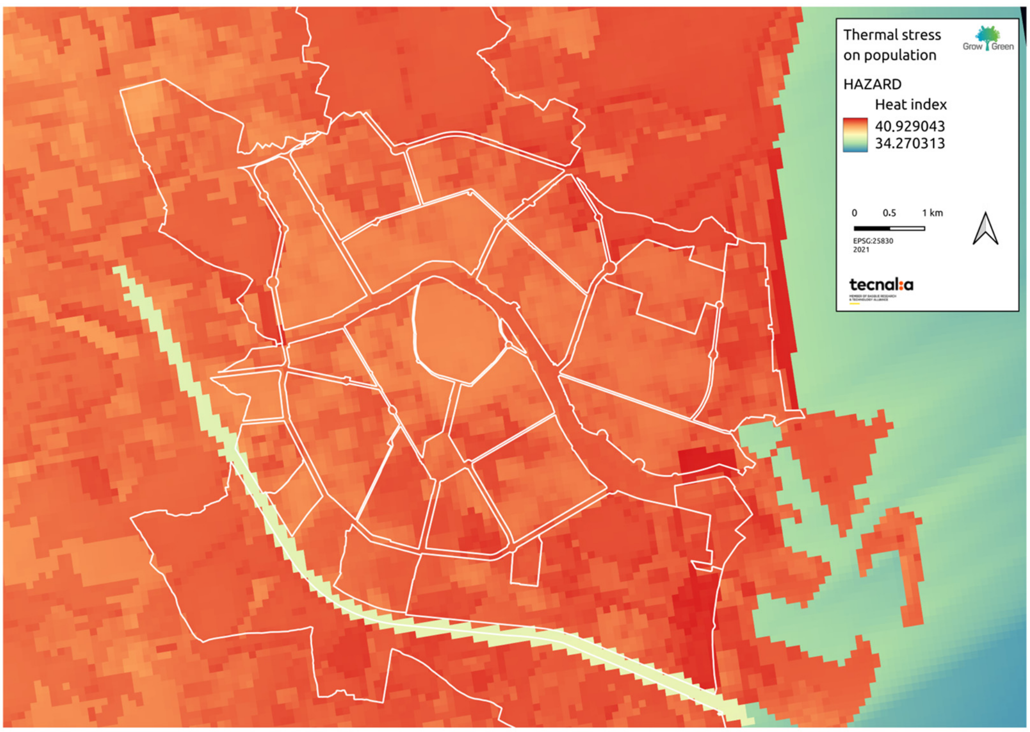

Figure 9. Spatial distribution of thermal stress in the city of València. Source: Own elaboration.

The resulting maps of the analysis of exposure, vulnerability, as well as the subcomponents of sensitivity and adaptative capacity are shown in Figures 10–13. The functional areas with the highest exposure were 07, 03, 05, 14, and 17, while those with the greatest vulnerability were 02, 03, 13, and 23 due to their high sensitivity and low adaptative capacity.

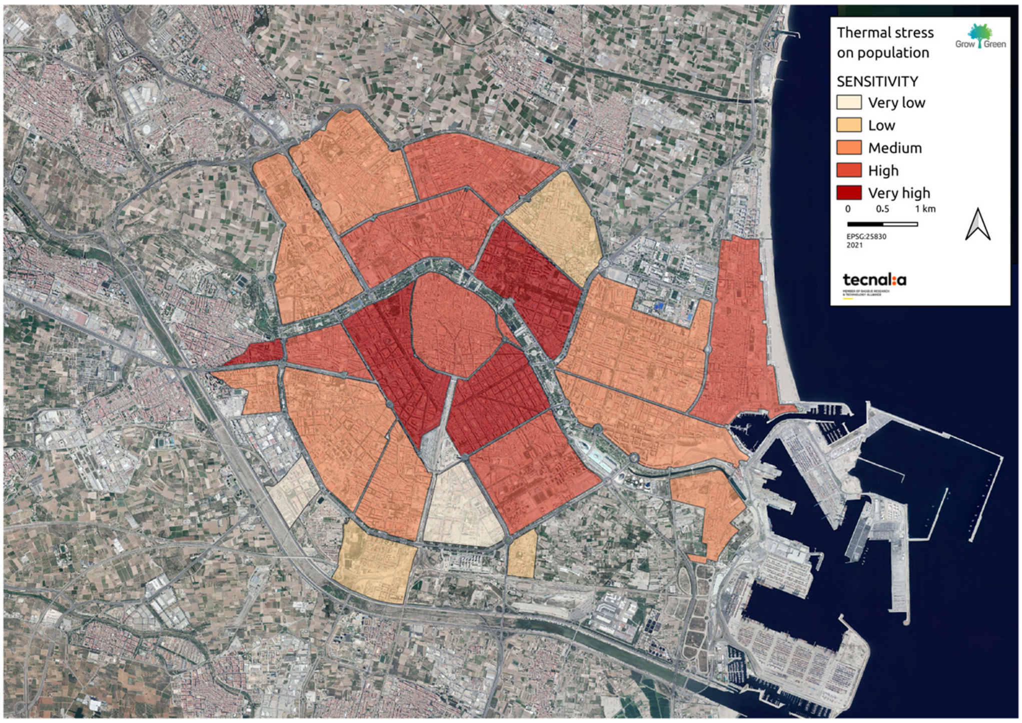

Figure 10. Results of the vulnerability assessment of the functional areas of València against thermal stress—Sensitivity. Source: Own elaboration.

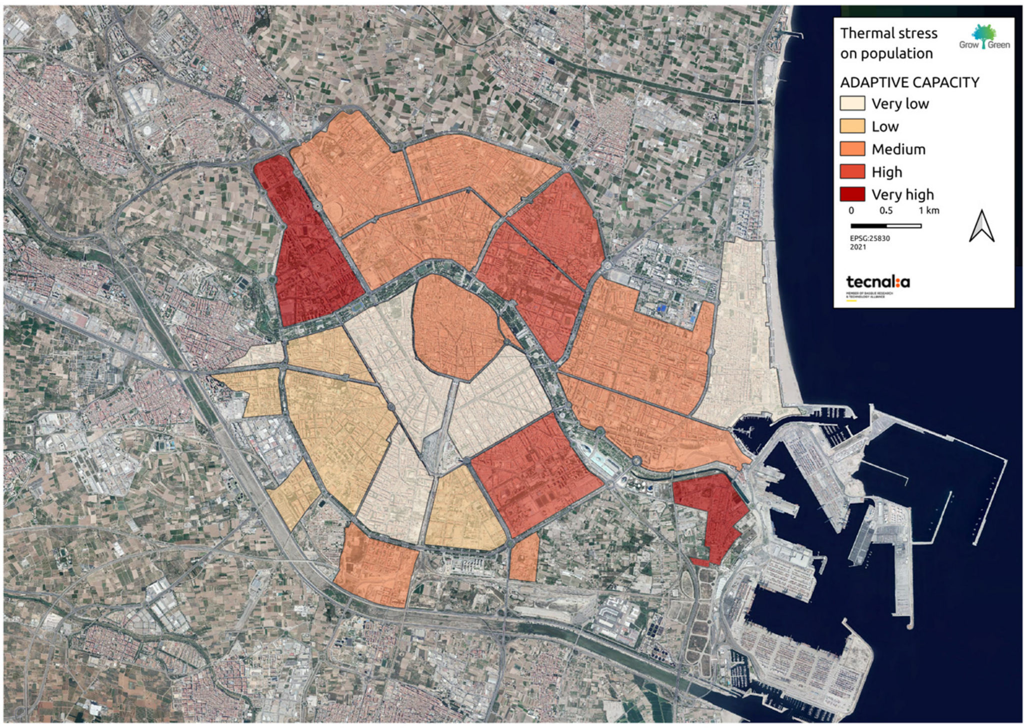

Figure 11. Results of the vulnerability assessment of the functional areas of València against thermal stress—Adaptive Capacity. Source: Own elaboration.

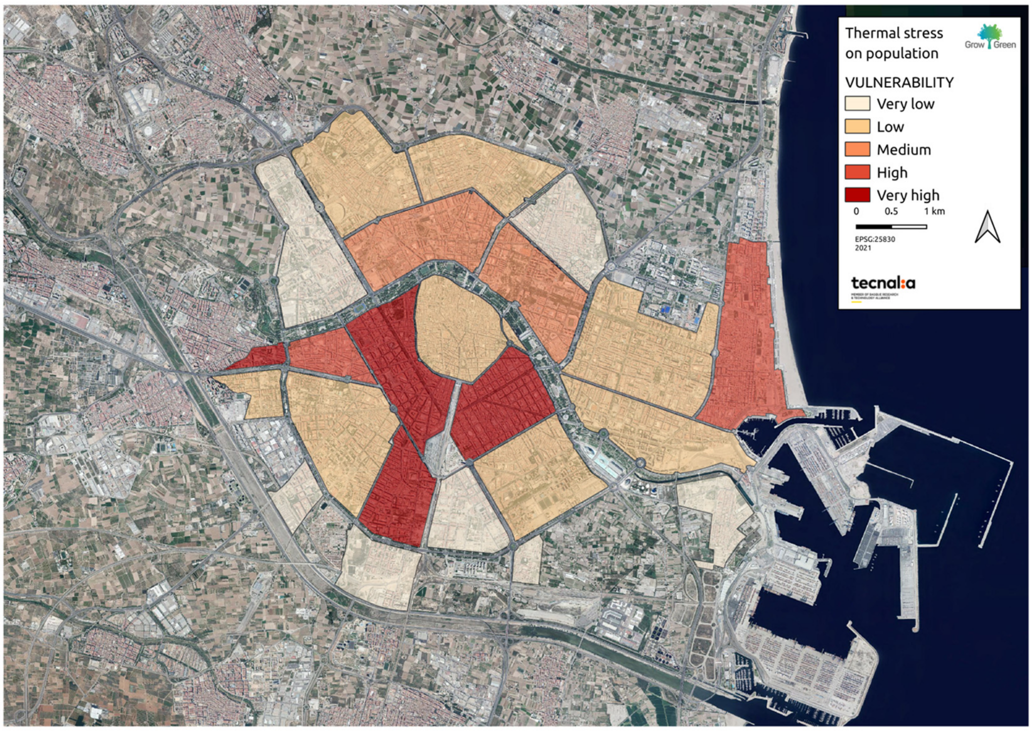

Figure 12. Results of the vulnerability assessment of the functional areas of València against thermal stress—Vulnerability. Source: Own elaboration.

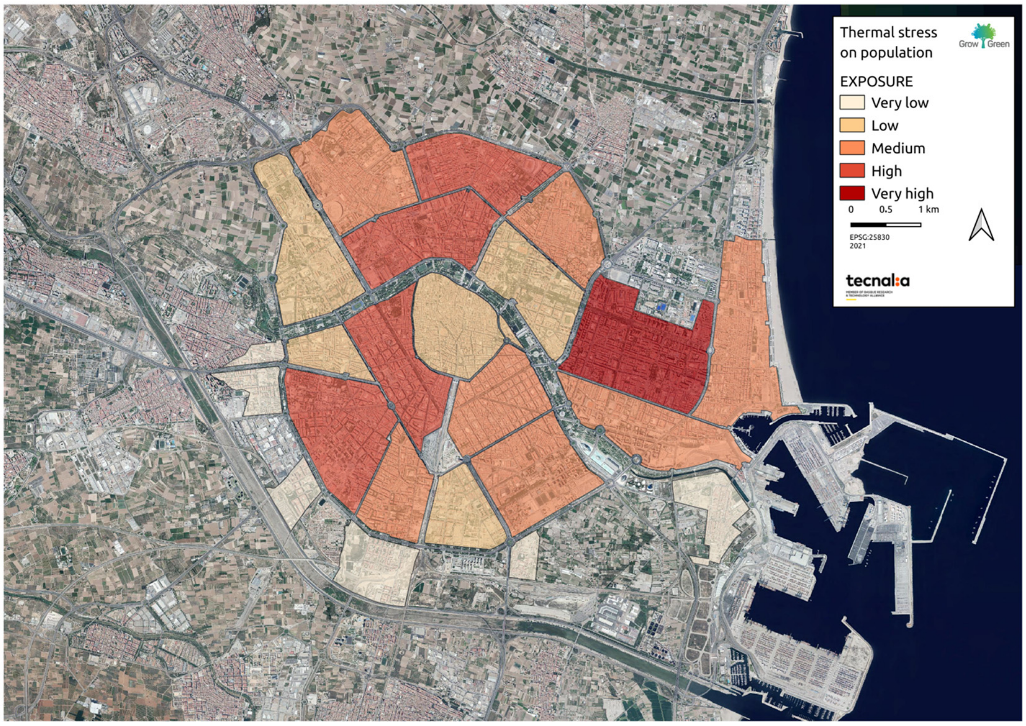

Figure 13. Results of the vulnerability assessment of the functional areas of València against thermal stress—Exposure. Source: Own elaboration.

Finally, the risk level was obtained after integrating the components of hazard exposure and vulnerability, as shown in Figure 14.

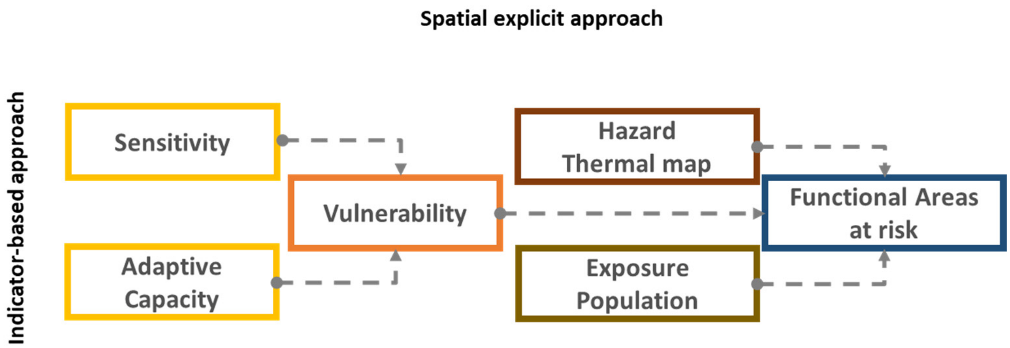

Figure 14. Integration of the different components of risk. Source: Own elaboration.

Five out of the 23 functional areas presented high risk due to thermal stress on the population: 02, 03, 07, 08, and 13 (Figure 15).

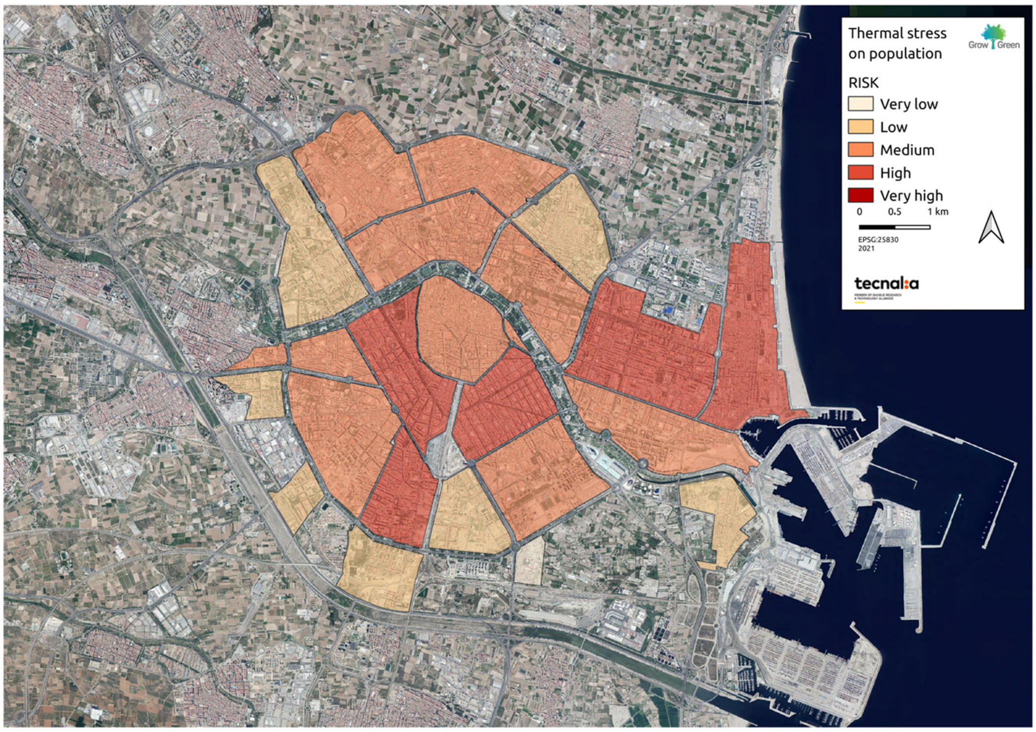

Figure 15. Risk assessment of the functional areas of València against thermal stress on human population. Source: Own elaboration.

For these functional areas in which the assessment revealed significant levels of risk, an analytic summary sheet was prepared (Figure 16) describing the contribution of each indicator to the components of risk and the values obtained in the area.

This analytic summary sheet was a valuable tool that qualitatively examined the intrinsic features of the functional areas and the neighborhoods within, explaining their risk so that tailored actions could be designed to successfully reduce the risk and increase resilience.

The results of the spatially explicit risk assessment facilitated the elaboration of guidelines and recommendations to inform structural (city wide) and detailed urban planning.

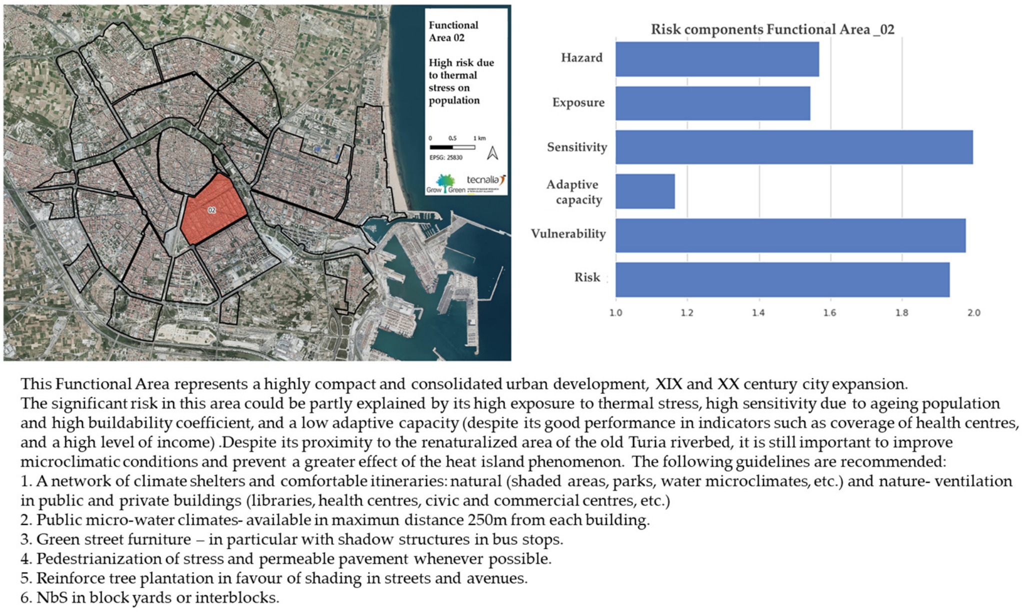

Figure 16. Example of a risk analytical summary sheet by functional area. Source: Own elaboration.

The guidelines and recommendations for city-wide structural planning could be summarized as follows:

- Perform tailored studies at the city scale for the analysis of climate-related hazards and the associated risks, prioritizing the following: flash floods, water scarcity, and forest fires.
- Define and include in the General Urban Development Plan the minimum content and basic orientations for undertaking vulnerability and risk assessments when elaborating development planning instruments (partial plans, special plans, etc.), in new development areas and/or regeneration projects.
- Identify the priority areas of action for the implementation of NbS, considering their vulnerability and climate risk as well as their maximum potential for deployment of NbS. The priority areas of action can be included in the progress documents of the General Urban Development Plan as well as the related strategic environmental reports.
- Elaborate opportunity mapping of green infrastructure and NbS deployment in the city, including the capacity to implement different types of NbS for climate resilience [37].
- Define synergetic actions between adaptation and mitigation measures.
- Emission proof the adaptation measures to identify potential mal-adaptations or conflicts with mitigation measures.
- Identify areas in the city with increasing energy demand due to climate change-linked climatization/household or industry air conditioning.

Specific recommendations were also defined to inform the development planning guidelines in functional areas for which the assessment of thermal stress revealed more significant risk in order to reduce their vulnerability and increase their adaptative capacity, considering NbS as the main adaptation options (Table 2).

Table 2. Summary of recommendations for detailed planning in functional areas with significant risk for the consideration of NbS as adaptation measures against thermal stress. Please note that the recommendations for detailed planning of the functional areas with significant risk do not address the role of albedo, emissivity, and other physically measurable quantities of used or proposed materials and surface of buildings. This was beyond the scope and objective of this research. Source: Own elaboration.

Functional Areas	Diagnosis	Recommendations for NbS Deployment
Historic centre, high-density urban consolidation, compact, residential, commercial, administrative development		
	These areas represent the historical centre of the city, with a compact urban fabric. The aims in these areas in relation to climate resilience are to improve microclimatic conditions and prevent the deterioration of green spaces. These aims also apply to future construction and renovations.	Design a network of climate shelters and comfortable, cool, and shady pedestrian routes. Cold islands: water microclimates—publicly available at a maximum distance of 250 m from each building. Green urban furniture—for example, conditioning of public transport stops.
High-density consolidated urban, compact, residential, commercial, administrative development		
	These areas represent compact urban fabric. The aims in these areas in relation to climate resilience are to improve microclimatic conditions and prevent the deterioration of green spaces. These aims also apply to future construction and renovations.	Pedestrianization of streets and permeable pavement on roads, sidewalks, parking spaces. Wooded—shading elements. Intensive cooperation with local actors.
Consolidated urban-residential garden environment		
	In the case of the city of València, this is a critical area due to its need for permeability with the surroundings of the orchard, city parks, farmland. Natural areas (forests, watercourses, alluvial plains).	Implementation of green and blue adaptation measures as a priority to increase connectivity in the urban–rural interface. Energy efficiency measures and sustainable building in new developments including material selection during the construction and renovation of buildings and public spaces to minimize secondary heat generation and maximize environmental cooling. Effective green management—preservation of high-quality areas (i.e., orchard) and restoration of green areas that allow connectivity with the peri-urban and rural environment of the orchard. Guarantee the connection between urban and rural areas, specifically with the orchard area. Use of the re-naturalization of linear infrastructures as ecological connectors. Promote ecosystem services in protected natural areas. In areas where the functional use of the area allows further construction, this should be done on the condition that it does not negatively affect the microclimate in surrounding areas with higher levels of risk.
Peri-urban facilities, infrastructures		
	Mainly residential areas, single-family houses, equipment.	Local construction/change of functional use must not reduce thermal comfort, so NbS must be prioritized. Energy efficiency measures and sustainable building in new developments including material selection during the construction and renovation of buildings and public spaces to minimize secondary heat generation and maximize environmental cooling. Permeable pavements in surface car parks.

4. Discussion

The vulnerability and risk assessment undertaken on the functional planning areas for the city of València provides relevant information for the planning process in the revision of the General Urban Development Plan, which was still under the approval process at the time of the writing of this research, in order to prioritize those areas that may require special attention as they show significant levels of risk in the face of adverse climatic events. In these areas, planning could condition certain land uses and activities to reduce their exposure or deliver NbS aimed at improving thermal comfort, therefore guaranteeing the health of the population, mainly of the most vulnerable groups.

This applied research work focused on heat stress in urban areas, being one of the priority areas identified by the Climate Adaptation Strategy of the city of València. The spatial information on the climate hazard due to an increase in temperature made it possible to generate spatial distribution maps of climatic indexes with a resolution that allowed vulnerability and risk studies to be conducted at the urban and suburban (district) scales, thus providing data to inform appropriate adaptation and urban intervention decisions.

Five out of the 23 functional areas presented high risk due to thermal stress on the population. This high risk was explained by the combination of high levels of hazard, exposure, and vulnerability. Indicators related to buildability, the efficiency of the urban fabric, and the population over 65 years contributed to the sensitivity of these areas. On the other hand, the level of civic association involvement, ratio of public facilities, free spaces, connection with the garden, and income per household partially explained their low levels of adaptative capacity.

Our results, together with those of other studies related to health [6,17,24,36,39], suggest that increasing the tree coverage should be combined with other interventions to produce larger temperature reductions, thereby having greater beneficial effects on health—particularly for cities with low cooling capacity, where increasing the tree coverage would not substantially reduce the temperature. This implies changing ground surface materials, structural interventions, land use, mobility, and interventions in buildings. At both the structural and development planning scales, the deployment of NbS through planning could determine the scope of content anchored in regulations and/or ordinances or as guidelines and recommendations.

Having said that, we recognize some limitations in the data used and methods applied. In relation to the characterization of hazard, other climate indexes could have been used, such as heat waves, which would allow better assessment of extreme events. However, considering the purpose of this research, which was the inclusion of climate change considerations into the urban planning process, the consideration of heat stress distribution was considered more appropriate.

The lack of data on air temperature at the district level (<100 m resolution) prevented making decisions on the heat impact on buildings, indoor comfort, and energy demand.

The database of indicators used in this research for the vulnerability assessment could have been enhanced by including additional physical, social, and socio-economic indictors beyond those in the Spatial Planning Guidelines, but this would have required gathering and processing of high-resolution data, which was beyond the scope of the research.

The city of València currently lacks a comprehensive, spatially explicit climate risk study that addresses, in addition to heat stress, other climate-related hazards. This comprehensive analysis would allow better informed planning and urban management decision-making, both in general and development planning, as well as the prioritization of climate adaptation actions. It is suggested that studies be conducted on climate vulnerability and the risks around the main hazards identified in the city using a spatially explicit approach, either the functional areas defined in the PGOU or neighborhoods, districts, or others, such as:

- Combined hazard studies: air quality and urban climate on population health.
- Water stress and footprint on economic activities (e.g., tourism)

- Flooding due to surface runoff associated with extreme precipitation events affecting population, transportation, and economic activities.
- Flooding due to sea level rise and waves in the urban environment.
- Forest fires in urban–rural fringe.
- Vulnerability and risk studies at the suburban level for the different impact chains associated with climate change would allow the identification of priority action areas, which would require municipal resources and urbanization, or regeneration interventions aimed at reducing vulnerability and risk by implementing better informed adaptation measures.

The assessment was carried out at a time of opportunity, not only due to the revision process of the Plan itself but also in light of the new Green and Biodiversity Plan, which is currently under development. In this sense, the vulnerability and risk assessment can contribute to València's strategic, in-depth reflection on its climate action roadmap towards adaptation.

The experience in València shows that, to ensure growth towards a more pluralistic approach, it is indisputable that urban planning teams are well positioned to assume the role of facilitators and determinants of change. Not only do they have a broad spatial understanding of the urban area in question, but they often work at the interface of both the environment and the market and are therefore able to explore new forms of green investment.

The renaturation of cities through a greater emphasis on the use of NbS also potentially offers urban areas the opportunity to generate multiple environmental and socioeconomic benefits.

Local governments, therefore, have a key role in designing projects that can help transform urban areas through more sustainable solutions. However, new pathways for NbS adoption will require substantial government commitment.

5. Conclusions

This case study, which was developed hand-in-hand with the involvement and validation of municipality officers of different departments, clearly exemplifies how urban thermal stress maps combined with spatially explicit socioeconomic data can provide useful information for assessing and quantifying vulnerability and climate-related risk. Applying this approach to benchmark a given sample of suburban-scale spatial units offers crucial facts to inform urban planning processes, allowing the prioritization of where to apply different type of measures. Among other climate adaptation options, NbS offer a cost-effective approach that additionally provide multiple co-benefits [40]. Predefining NbS classes for better integration into different urban typologies could orient urban interventions in prioritized areas.

In the context of climate change, heat stress has high importance to many cities worldwide and specifically in Europe [41]. This systematic approach, therefore, could be transferable and of use in other geographies and contexts facing the same climate challenges.

Further research could be developed in relation to: (i) applying this same approach to address other climate hazards in urban planning; and (ii) better understanding of formal planning mechanisms that could facilitate the deployment of this approach in different planning frameworks.

Both the results of this research as well as the further research suggestions could feed key current policies in Europe, such as the implementation of the EU Adaptation Strategy and the EU Mission on Adaptation to Climate Change [42].

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