D1.2 Monitoring report (Guidelines)

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Authors	HEREON: María Máñez, Chiara Bernardini POLIMI: Andrea Arcidiacono, Grazia Concilio, Matteo Giacomelli, Maryam Karimi, Silvia Ronchi, Stefano Salata
Collaborators	
Point of Contact	
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Revision History

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V0.3	29/03/2024	Integration of the internal reviewer Nicola Morelli's comments

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Executive Summary

"Deliverable 1.2 – Monitoring report (Guidelines)" is the second one planned for "WP1 - Urban Planning and Climate Neutrality Evaluation" within CLIMABOROUGH project, which aims at defining a common framework of Key Performance Indicators (KPIs) to measure the project's impacts and to guide urban planning strategies towards Climate Neutrality. In this respect, "Deliverable 1.1 – Monitoring tool of CLIMABOROUGH project" provided a work-in-progress update on the development of the Urban Planning Framework for Climate Neutrality.
This report (D1.2) constitutes one of the main outcomes of two Tasks of WP1: "Task 1.3 - Monitoring tool: measuring progress in climate neutrality" and "Task 1.5 - CLIMAHUBS Impacts Assessment". It presents the rationale behind the structure of the sets of KPIs composing the tool and provides guidelines for its application in cities.
The project's impacts analysis will show whether the approach and the overall implementation have been useful.
A set of KPIs are quantified with the aim to facilitate the effective monitoring and quantification of the climate neutrality action including the CLIMABOROUGH actions and impacts. A series of broad stakeholder consultations will also look into long term impacts which cannot be gauged through the KPIs. Based thereon, conclusions can be drawn for both the up-scaling of procedures developed within the project in the pilot cities and for the design of future project evaluations in a climate-resilience (and city-specific) context.
At the actual stage of the project, pilot cases and sandboxes have not seen their kick-off yet. Therefore, the main objectives of this Deliverable are i) to outline the methods adopted in the design process of a comprehensive set of KPIs as common metrics for the evaluation framework of CLIMABOROUGH project; ii) to identify the specific indicators that will be employed to measure the outcomes of the climate Neutrality actions and including impacts of the project and iii) to provide guidelines for the application of the CLIMABOROUGH s assessment and monitoring framework in cities.
The deliverable also include the description of a Capital related reference to identify the structural and functioning asset of each city.

Furthermore, attention has been paid to designing this instrument in such a way that it can be easily applied and re-applied by local administrations independently. The aim is actually to expand the function of the CLIMABOROUGH assessment and monitoring tool: it will not only be used by the WP1 research teams as a control-tool to monitor the advancements of CLIMABOROUGH project, but rather all the 14 CLIMABOROUGH partner cities will be provided with a tool for the self- assessment and monitoring of their progress towards achieving climate neutrality.
With this in mind, the construction of the tool includes testing the prototypes developed step-by-step throughout the whole development process and in various cities, organizing different KPIs co-design workshops with the 14 CLIMABOROUGH partner cities' representatives and testing the final version in 4 pilot cities (Torino, Cascais, Grenoble and Differdange) to achieve the final validation of the KPIs.

The ultimate goal goes far beyond the CLIMABOROUGH's project objectives and its time horizon: our ambition is to design an innovative climate neutrality self-assessment and monitoring tool which can be employed by cities all around the world

to identify their weaknesses and accordingly select ad-hoc actions and measures to advance towards the achievement of climate neutrality.

The document is divided into 3 sections:
Section 1 provides an introduction to the CLIMABOROUGH assessment and monitoring tool, including the design process of the tool, the presentation of the approach adopted in the definition of the Key Performance Indicators (the “capital approach”) and the introduction of the concept of “Climhubs”, a key concept within the project.
Section 2 describes in detail the sets of Key Performance Indicators divided into six clusters, corresponding to the six ”capitals”.
The third section (**Section 3**) deals with the testing phase of the tool presented in this Deliverable. It reports the results of the first tests conducted in close collaborations with the partner cities of the CLIMABOROUGH project: the application of the indicators related to climate neutrality governance in the City of Krk, the assessment of the Eco-system capacity KPIs in Turin and the participatory design of KPIs through the proposal of a workshop held in Maribor at the CLIMABOROUGH General Assembly in March 2024.

Introduction: relation with previous Deliverables in WP1

The CLIMABOROUGH "WP1 - Urban Planning and Climate Neutrality Evaluation" is devoted to the development, testing and validation of an urban planning framework to reduce the uncertainty of mitigation and adaptation policy measures' impacts on urban systems.
It starts with the synthesis and systematization of the complex system of different plans related to climate change management that refer to different sectors, enabling collaborative work on problem identification and solutions design. Furthermore, WP1 foresees the design of a KPI-based tool intended to monitor and measure project's impacts and progress towards climate neutrality by operationalizing the Climate Neutrality Assessment framework that includes also the specific actions developed within the CLIMABOROUGH project. Finally, Urban Planning Handbooks will be produced for both expert and technical subjects (professionals, policymakers, urban managers) as well as laypeople (citizens, civic organizations, etc.).
The selection and the structuring of the sets of Key Performance Indicators (KPIs) to measure the progress towards climate neutrality and the contribution of CLIMABOROUGH project along its duration is based on the CLIMABOROUGH Urban Planning Framework for Climate Neutrality (UPF4CN) already presented in "Deliverable 1.1 – Monitoring tool of CLIMABOROUGH project", represented in Figure 1.

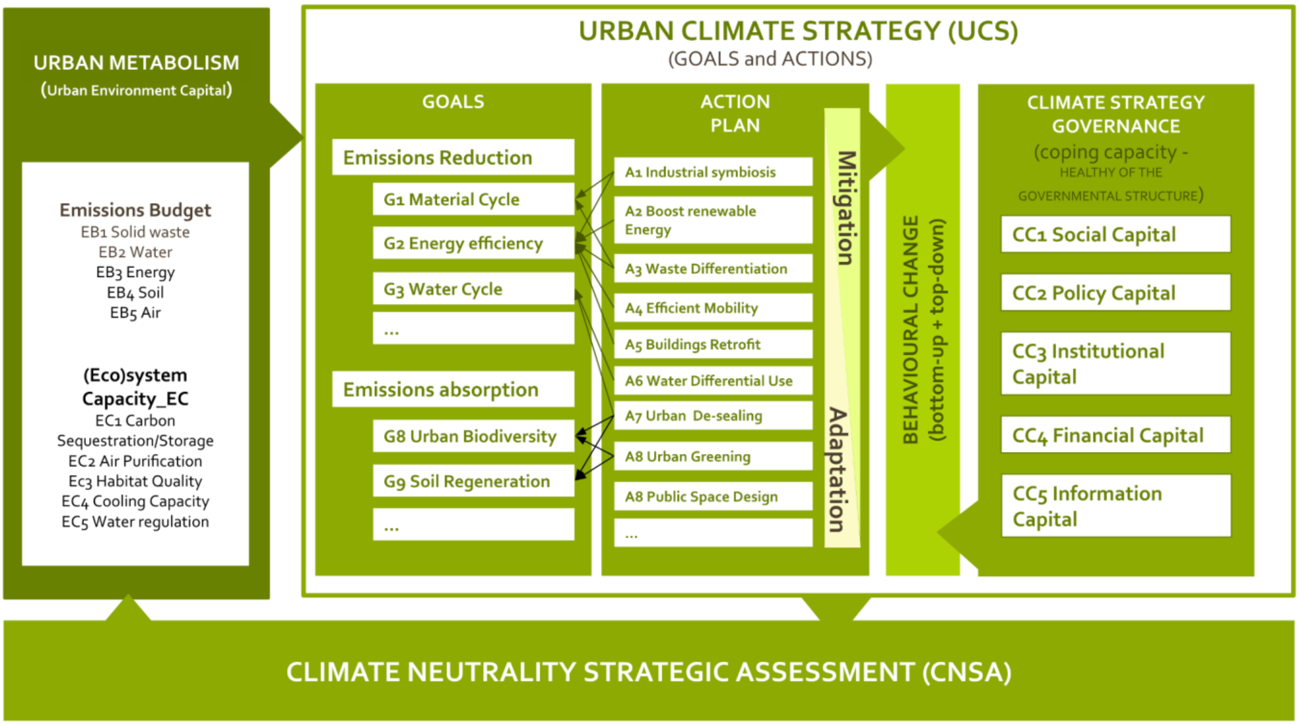

Figure 1: The CLIMABOROUGH Urban Planning Framework for Climate Neutrality (UPF4CN). Adapted to the Capital logic from Deliverable 1.1: Monitoring tool of CLIMABOROUGH project.

The UPF4CN consists of two blocks. In the first block, (Urban metabolism) cities are conceived as systems that, from one side, produce pollutants contributing to the worsening of climate factors and, on the other side, are able to contribute to the absorption of those pollutants. Accordingly, the first sub-block is labeled as “Emission Budget” in relation to the urban emission budget by the urban system. We labeled the second sub-block “Ecosystem capacity” referring to those functions that the city can perform in relation to carbon sequestration, carbon storage and, in general, pollutants reduction. The block called “Ecosystem capacity” includes Ecosystem Services (ES) (Costanza et al., 1997) relevant for urban planning strategies.

The second block is related to the Climate Neutrality Strategy and includes the general goals and the Action Plan as well as the Climate Strategy Governance. The general goals arerelated to two general perspectives: emissions reduction and emissions absorption. Emissions reduction entails minimizing pollutant inputs into the urban systems and addressing issues such as material cycles, energy efficiency, water management, air pollution, and more. On the other hand, emissions absorption refers to urban biodiversity, soil regeneration, and similar broad goals. To achieve these goals, cities are developing a comprehensive range of actions (an Action Plan), each with varying relevance and contribution in targeting the desired outcomes. These actions are collectively referred to as “ Action plan”, and they improve both emissions mitigation and cities’ adaptation.
The achievement of climate neutrality is a complex process that varies significantly from one city to another. How cities approach and manage this journey is highly relevant and we refer to this approach as “Climate strategy governance” (a second portion of the second block. Climate strategy governance encompasses the city's capacity to cope with the challenges associated with climate change management. To assess a city’s coping capacity we investigate the health, the fitness of a city's governmental structures and processes.

Many approaches to governance assessment were broadly recognized as valid and have resulted useful tools to be applied in reality but they all show a non-negligible limitation with regard to the intent of CLIMABOROUGH project: they are usually designed to be applied with the support of an intermediary subject (consultants, experts, etc.). CLIMABOROUGH aims instead at improving cities’ awareness, empowering local governments in the face of the transition towards climate neutrality, boosting cities’ action capacity through the provision of re-applicable tools which can be used independently. It was hence considered necessary to develop an *ad-hoc* tool in order to enable cities’ governance self-assessment.
This is based on the “capital approach”, theorized by Sen (1983), Bebbington (1999) and Goodwin (2003) and applied by Máñez et al. (2014), among many others, to assess cities’ governance performance in dealing with natural hazards.
The assessment and monitoring tool presented in this report (Deliverable 1.2) adopts the concept of “capitals” while building on the UPF4CN described above: the sets of KPIs will be applied to measure the impacts of the mitigation and adaptation actions (second block in the UPF4CN) implemented by the partner cities on the cities’ Climate urban metabolism (first block in the UPF4CN) and on the Climate strategy governance (third block in the UPF4CN).
The Urban Planning Framework for Climate Neutrality (UPF4CN) and the CLIMABOROUGH assessment and monitoring tool will undergo validation through their application in 4 partner cities belonging to 2 different Climahubs (Torino, Cascais, Grenoble and Differdange).
These tests will allow to identify the weaknesses and the critical aspects of our approach and, if necessary, to accordingly adjust it.

1. The CLIMABOROUGH assessment and monitoring tool: assessing cities progress towards Climate neutrality

1.1 The Capital approach

The concept of "capitals" was originally employed to analyze sustainable development and sustainability livelihood and basically refers to "the assets, capabilities, properties or other valuables which collectively will represent the good functioning" (Máñez et al., 2014) of a governance model. The maintenance or the enlargement of capitals might contribute to the maintenance or the improvement of the capability of a city to tackle environmental hazards and fulfill climate goals.

The actions to address climate change require coordination among multiple stakeholders, groups, departments, sectors, policies and, therefore, robust governance models to manage complex and interrelated processes. Tackling climate change and adapting to current and future impacts is "fundamentally a governance challenge" (OPM, 2018). Máñez et al. (2014) agree that assessing governance structures is of primary importance for maintaining cities' capability to react to natural hazards, detecting the weaknesses that might need to be addressed and evaluating local governments' performance over time. It can be claimed that governance is a necessary-but-not-sufficient pre-condition for climate goals fulfillment and, more specifically, for climate neutrality achievement.

The Intergovernmental Panel on Climate Change (IPCC) identifies the "limited integration or coordination of governance" as a major constraint that interacts to impede climate measures planning and implementation (IPCC, 2023).

There is large consensus that climate change management is a "wicked" (Alford et al., 2017) or even "a super wicked" (Lazarus, 2008) issue. Bovair et al. (2009) even state that "trying to define public governance seems to open Pandora's box". This "wickedness" of climate change governance derives from i) the high uncertainty surrounding climate change effects and impacts on urban systems; ii) the intrinsic complexity of urban systems; iii) the consequent difficulties in evaluating the potential beneficial impacts of planned mitigation and adaptation measures and in assessing the effectiveness of the already implemented actions on risks reduction; iv) the heterogeneity of the involved stakeholders; v) the lack of resources to finance actions; vi) the influence of cultural issues and the lack of trust in politicians; vii) the inadequacy of regulatory frameworks; viii) the insufficient quality of climate information and/or of information management practices and tools; and other factors.

The capital approach theorized by Sen (1983), Bebbington (1999) and Goodwin (2003) and applied by Máñez et al. (2014), among many others, to assess cities' governance performance in dealing with natural hazards is a reading of reality that can help decipher this complexity.

Originally, the capital approach differentiated between five capitals:

1) Social capital;
2) Human capital;
3) Financial capital;
4) Natural (environmental) capital;
5) Man-made capital.

Máñez et al. (2014) proposed the introduction of the "Political capital", seen as "the capability of institutions to enact rules, laws or frameworks that might change the course of actions" (Máñez et al., 2014).
We further adapted and adjusted the capitals on the basis of the specific scope of the research activities carried out within the CLIMABOROUGH project and proposed this final configuration:
1)Urban environment capital;
2) Social capital;
3) Institutional capital;
4) Policy capital;
5) Financial capital;
6) Information capital.

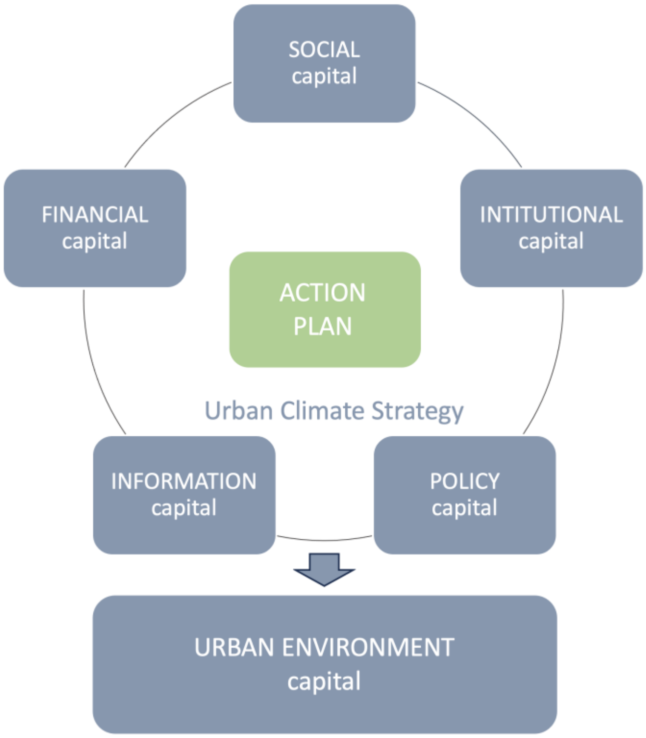

Figure 2: The six capitals of climate neutrality as a framework for cities' self-assessment and CLIMABOROUGH project monitoring. Adapted from Máñez et al. (2014).

Hereafter, we report the rationale behind the reading of climate neutrality governance in cities through the lens of the proposed six capitals.
The Urban environment capital represents the entire climate urban metabolism and takes into account both the Emission budget and the Ecosystem Value. It practically considers the entire city (its physical asset and functions) as a form of capital per its capacity to produce a metabolism which should, as much as possible, move towards circularity (digesting the most of the waste the city produces). This capital allows the identification of the goals of the Action plan and at the same time is modified by the Action plan and the five governance related capitals towards circularity.
The Social capital focuses on the relationships between multiple stakeholders and the shared norms and values that qualify a certain society. It contributes much to the capacity of local governments to implement effective climate measures and achieve climate neutrality, as well as on the well-being level of citizens.

The Institutional capital in our framework includes the governmental processes and procedures performed by political and administrative figures, which write and apply laws, strategies and plans and implement policies. The term “institution” here refers to “the rules and customs of a special group of similar interest” (Máñez et al., 2014), whereas, in this case, the common interest is achieving climate neutrality. It is closely related to the principle of “institutional fitness”.
This capital also includes individual skills and competences. In the case of local governments, it results from the sum of employees’ and external collaborators’ skills and competences.
The Policy capital enables the assessment of the regulatory framework related to climate change challenges management and, more in particular, to climate neutrality governance.
The Financial capital corresponds to the most common meaning of the term “capital”: tangible resources and all types of wealth (funds, substitutions, compensations etc.) that are provided to local governments by banking industries, private businesses or by means of public funding programs at the international, European, national or regional scale.
Finally, we decided to add the Information capital. This is closely linked to information management, tools and procedures and it is a cross-cutting aspect in every research fields related to human systems. Information management is indeed seen as one of the pillars of climate neutrality strategies. An optimal exploitation and interpolation of the available climate and non-climate information enables informed decisions in complex anthropic systems.
Dealing with the climate neutrality challenge led to the application of the capitals approach for the development of the KPIs-based assessment tool with the purpose of monitoring and evaluating improvements in cities’ capacity along the CLIMABOROUGH project, after the implementation of mitigation and adaptation measures and actions and the application of mitigation and adaptation solutions.
The reorganization of the sets of KPIs in six capitals gave as output the final version of the CLIMABOROUGH impacts assessment and monitoring tool.
Given that the proposed tool includes both “common” indicators (broadly agreed in reference literature) as well as “new” ones in order to incorporate underrepresented climate neutrality aspects, it is not surprising that new metrics were required to measure the performance of cities in such unexplored dimensions.
In view of this, some metrics have been assigned to each indicator but will be subject to further updates based on the feedback provided by the pilot cities’ that will test the CLIMABOROUGH impacts assessment and monitoring tool (supported by the CLIMABOROUGH research team members of WP1).
The same goes for thresholds, whereas they were extracted by reliable literary sources, but they will require to be further investigated and refined in the light of cities’ feedback.
A separate remark regards weights assignment to each indicator: the scope of this tool is not ranking cities but rather detecting weak points in their governance models and processes and gaps in their tangible and intangible resources (capitals) in order to identify rooms for improvements and implementing effective climate measures to support cities’ in their transition towards climate neutrality. Thus, assigning weights to the different factors included in the framework would only be useful in terms of prioritizing actions in what would emerge to be the most important and impactful aspects of cities governance. Nevertheless, the different weight (the impact) of the different factors and indicators may depend on multiple reasons that are highly case-specific (city-specific).

1.2 Alignment with the Net Zero Cities approach

In the pursuit of climate neutrality for European cities, aligning project frameworks becomes essential. By integrating our Key Performance Indicators (KPIs) with the Comprehensive indicator framework of the Net-Zero Cities project, we ensure a unified approach to assessing progress. This alignment fosters a holistic evaluation, enabling cities to develop climate action plans grounded in a shared understanding. Our interpretation of "leverages" as “capitals” addresses cities' pre-conditions and resources in enabling effective climate actions. However, it's important to recognize that these pre-conditions are to be intended as necessary-but-not-sufficient for climate goals fulfillment and, more specifically, for climate neutrality achievement.

In Net-Zero Cities, the impact domains to monitor and evaluate in relation to the 2030 Climate Neutrality Action Plan implementation include:

- Monitoring of direct benefits (emission domains)
- Monitoring of indirect benefits (also known as co-benefits)
- Process monitoring of action portfolios and systemic levers, following defined transition pathways

The subdomains for Direct Benefits (reduction in GHG emissions) are aligned with the CDP/ICLEI GHG reporting framework, to facilitate data collection through existing reporting channels. The subdomains of Indirect Benefits take up the co-benefits of climate neutrality identified by the Net-zero cities project. Within the Climaborough project, they are included in the urban environmental capital.

On the other hand, the subdomains of Systemic Levers reflect the systemic levers described in the Theory of Change and correspond to the 5 capitals of governmental structure in Climaborough: Social, Financial, Institutional, Political, and Human Capital.

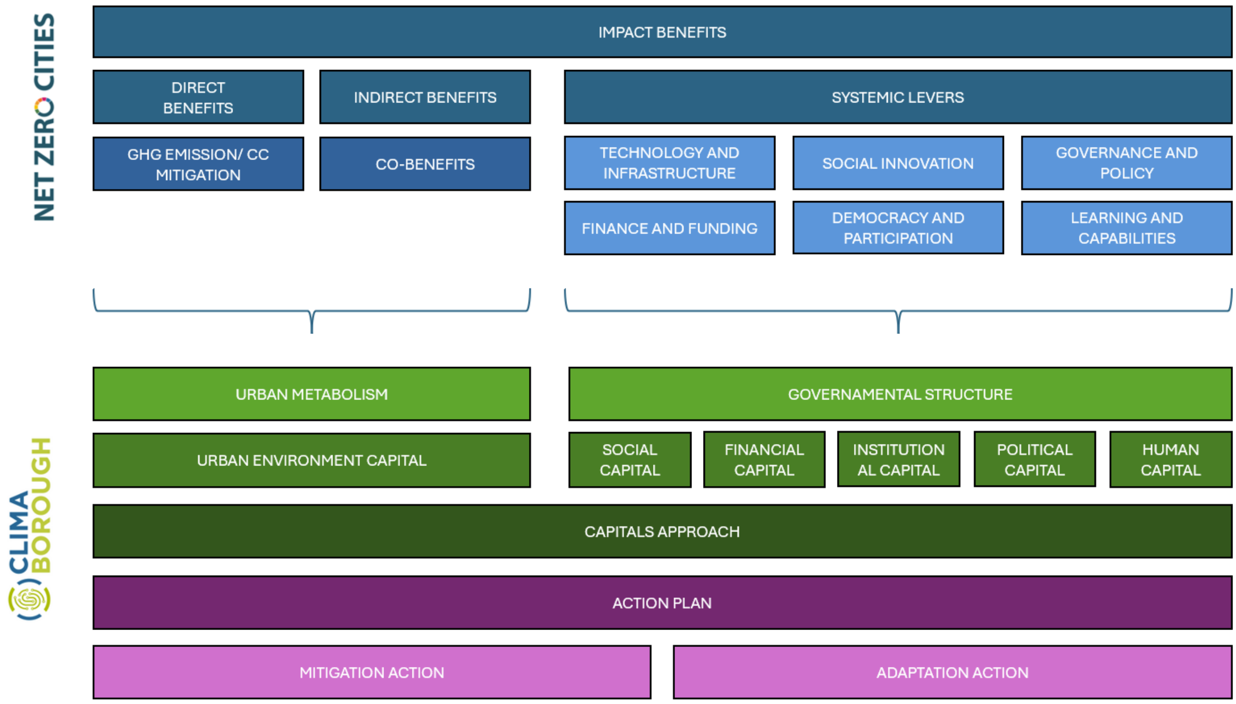

Figure 3: Coherence with the Net Zero Cities indicators into the CLIMABOROUGH assessment framework .

1.3 Designing the Capitals related KPIs

Deliverable 1.2 presents the rationale behind the structure of the sets of KPIs composing the CLIMABOROUGH assessment and monitoring tool and provides guidelines for its application in cities.
The description of the design process of the KPIs for assessing the CLIMABOROUGH project enables their complete understanding and their correct and conscious application. The process is hereafter simplified and synthesized in different steps (Figure 2).

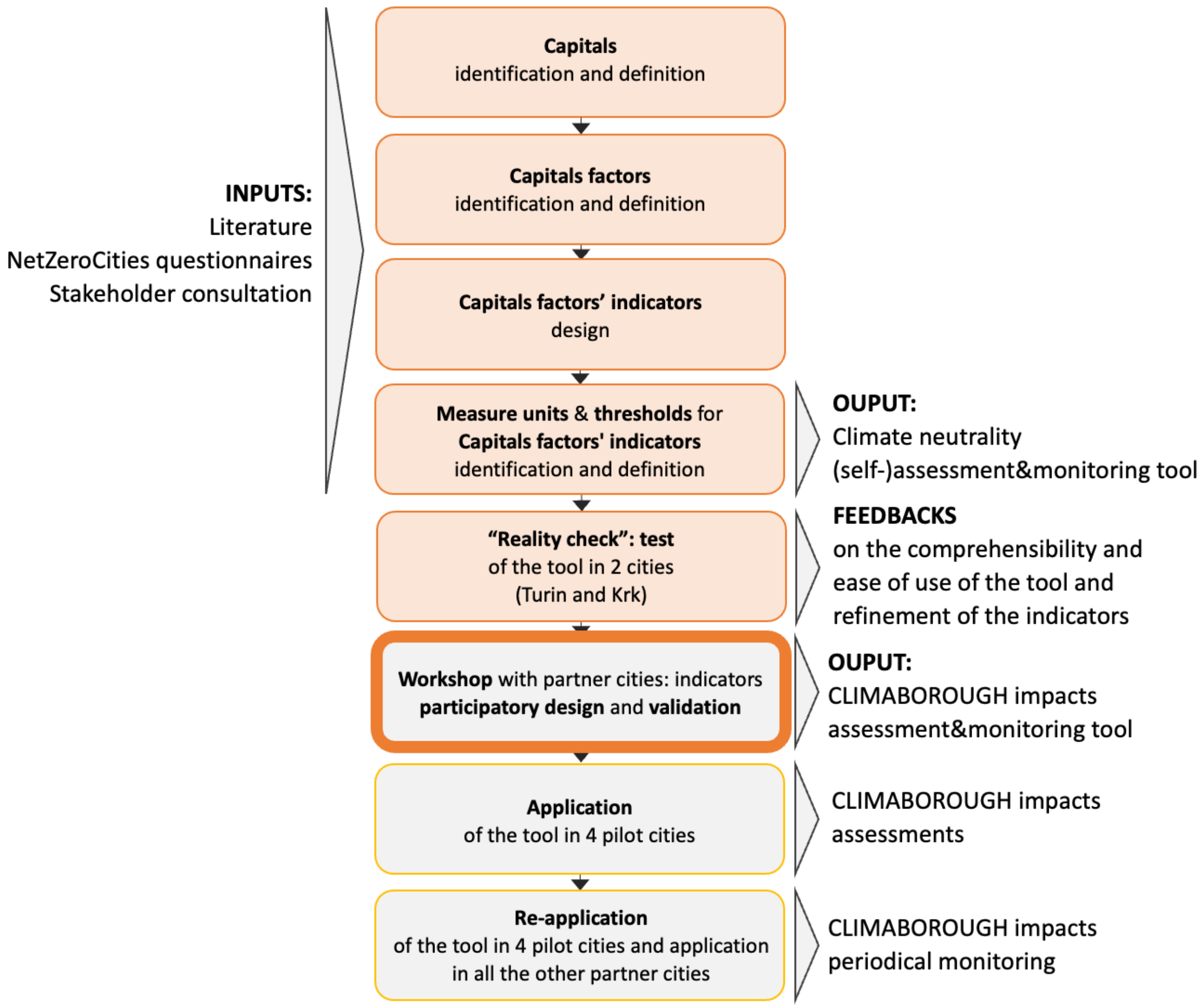

Figure 4: Steps in the construction of the capitals KPIs framework.

The first step in the construction of the CLIMABOROUGH project assessment and monitoring tool was the identification and definition of the five "capitals" that represent "the assets, capabilities, properties or other valuables which collectively will represent the good functioning" (Máñez et al., 2014) of a governance model. Each capital was broken down into factors, and different indicators are assigned to each factor.
The inputs for this initial structuring-phase of the sets of KPIs to be included in the tool were relevant literature on climate governance assessment methods and tools at the local scale, preliminary stakeholders consultation (CLIMABOROUGH partner cities and scientific partners) and NetZeroCities questionnaires[1].

The design of the sets of KPIs connected to the five capitals hence required the identification and definition of measure units and thresholds. The output of this phase was the CLIMABOROUGH Climate neutrality (self)-assessment and monitoring tool.
The final product consisted in a set of fillable tables similar to a survey in its ease-of-use: each indicator was formulated like a multiple-choice question that requires the respondents to tick YES or NO or to choose between few options (e.g. frequency in years or percentage under or above 33%).

The first prototype of the tool was tested in 2 cities: Turin (Italy) and Krk (Croatia).

[1] See Paragraph 1.2 of the present Deliverable: Alignment with the Net Zero Cities approach

In Turin we tested the indicators related to the Urban environment capital and, more in partiuclar to the Eco-system capacity: Carbon Storage, Air purification, Habitat quality, Cooling capacity and Water regulation. In Krk we proposed and explained to the city's representatives the rationale behind the KPIs related to the governance of climate neutrality, thus exploring: the Social capital, the Institutional capital, the Policy capital, the Financial capital and the Information capital.
In both of the cases, the tests were conducted in a face-to-face modality and in the presence of cities' representatives from different departments and with different expertise and competences.
The results of these tests are reported in Section 3 of this report in detail.
On the basis of these experiences, the sets of KPIs were adjusted and integrated.
The reorganization of the sets of KPIs gave as output the CLIMABOROUGH impacts assessment and monitoring tool. The structure of this new tool will be further described in the next sections of this Deliverable.

Attention has been paid to designing this instrument in such a way that it can be easily applied and re-applied by local administrations independently. The aim is actually to expand the function of the CLIMABOROUGH impacts assessment and monitoring tool: it will not only be used by the WP1 research teams as a control-tool to monitor the advancements of CLIMABOROUGH project, but rather all the 12 CLIMABOROUGH partner cities will be provided with a tool for the self- assessment and monitoring of their progress towards achieving climate neutrality.
With this in mind, the construction of the tool included organizing a KPIs participatory design workshop with the 12 CLIMABOROUGH partner cities' representatives. This was conducted in an in-presence modality at the CLIMABOROUGH General Assembly held in the city of Maribor (SL), on the 12th of March 2024. The scope of the workshop was explaining the structure of the tool (the differentiation of the proposed KPIs into six sets corresponding to six capitals), verifying the comprehensibility of the proposed KPIs, collecting the cities' feedbacks on their usefulness and soliciting suggestions for alternative/additional indicators to be integrated in the sets of KPIs. The KPIs will be accordingly adjusted and refined.

The next step in the process will be the application of the tool in 4 pilot cities chosen among the project partner cities: Torino, Cascais, Grenoble and Differdange.
The stakeholders which will provide the information required to assess the CLIMABOROUGH project are the primary source of inputs to the assessment and monitoring processes. Thus, the selection of subjects to be involved in the application of the tool directly influences the assessment outputs. This will be therefore a critical step which requires a previous knowledge of the different available "candidates" and an accurate evaluation of personal background, skills, role, level of involvement and engagement in climate neutrality related issues etc.
The people selected for this critical task are identified with the term "Key informants", which was already used by the Oxford Policy Management group in the report on Climate Governance Assessment (2018), among others.
The preferable number of Key informants will vary depending on the characteristics of each pilot city and its institutional and social context, as well as on the organizational structure of the local government: for example, the more fragmented is the structure (many different departments responsible for different issues related to climate neutrality),

the highest number of people will be required to answer the questions and provide information.
In the evaluation, the need for diversity of points of view in the respondents will also be taken into consideration and it will be balanced with time and resources available for the application of the tool.
Potential candidates to be Key informants may include:

- Local government political representatives;
- Local government technical representatives;
- Consultants working with local government on specific climate-related issues;
- Governmental agencies working on specific climate-related issues representatives;
- Non-governmental organisation (NGO) working on climate-related issues representatives;
- Academics and researchers working with local government on specific climate-related issues;
- Private sectors representatives collaborating with the local government on sector-specific climate-related issues.

While the co-design of the Capitals KPIs has been conducted with cities within a comprehensive approach together with the governance capital, the completion of the table related to the Urban Environment capital will be a city-by-city activity. It will be a process based on local data collection strategy and on available data and its granularity, on the urban functions, on the exposure to climate related critical events. It will be a context driven activities to be carried out together with data manager and with the subjects responsible for the manager and coordinators of the Climate Neutrality strategy.

Once the refinement of the tool will be completed, it will be periodically re-applied in the pilot cities to monitor their progresses towards climate neutrality throughout the whole duration of the project.
This periodical project's assessment will show whether the CLIMABOROUGH approach and the overall implementation have been useful.
Besides the 4 pilot cities, all the other partner cities not directly involved in the pilots will apply the CLIMABOROUGH impacts assessment and monitoring tool independently.
In fact, the tool was designed to be easy-to-use and applicable by local governments independently, without the intervention of intermediaries or consultants.

1.4 The "traffic lights" approach for the Governance related capitals

The CLIMABOROUGH assessment and monitoring tool is intended to be as much easy-to-use as possible, to allow its understanding and application by local governments that cannot count on high specific competences and expertise.
Other authoritative examples of governance assessment methods and tools share this choice: the European Climate Foundation chooses not to rank the indicators and applies no weighting, claiming that "establishing a hierarchy, ranking and/or weighting would need additional research and should involve stakeholders to support the final selection" (ECF, 2021).
For the same reasons, in the Climate Governance assessment methodology proposed by the Oxford Policy Management (2018), each of the dimensions are given equal weightage even if "in reality, some dimensions are more important than others" (OPM, 2018).

The assignment of indicators' values is based on the "traffic light" assessment methodology applied by Carmona (2016). Table 1 shows the final structure of the KPIs sets and the formulas employed to calculate the indicator values. The "Green" score (good performance) results from Fv/Ni, whereas "Fv" is the Factor value and "Ni" is the Number of indicators; the "yellow" score corresponds to G*0,5, whereas "G" is the Green score; the value of the red score is always 0 and results from G*0, whereas "G" is the Green score.
This approach is very easy to understand and the colour scale is graphically very intuitive.

Capitals	Value	Factors	Factor value	Code	Number of indicators	Indicator value			Metrics
						Green (Fv/Ni)	Yellow (G*0,5)	Red (G*0)	
SOCIAL	16,66	2.1 Participation	5,55	2.1.x	11 indicators	0,50	0,25	0,00	Y/N; frequency (years)
		2.2 Communication and knowledge	5,55	2.2.x	8 indicators	0,70	0,34	0,00	Y/N; frequency (years);
		2.3 Rules and norms of society	5,55	2.3.x	3 indicators	1,85	0,92	0,00	Y/N; yearly meetings; $
INSTITUTIONAL	16,66	3.1 Organizational structure	5,55	3.1.x	6 indicators	0,92	0,46	0,00	Y/N
		3.2 Skills and competences	5,55	3.2.x	6 indicators	0,92	0,46	0,00	Y/N; high-medium-low
		3.3 Transparency and trust in political actions	5,55	3.3.x	9 indicators	0,62	0,30	0,00	Y/N; high-medium-low; %; years; n° of people
POLICY	16,66	4.1 Regulatory framework	16,66	4.1.x	16 indicators	1,04	0,52	0,00	Y/N; %
FINANCIAL	16,66	5.1 Climate finance	8,33	5.1.x	4 indicators	2,10	1,04	0,00	Y/N;%
		5.2 Disaster funds/ Compensation of losses	8,33	5.2.x	7 indicators	1,20	0,6	0,00	Y/N; %; $
INFORMATION	16,66	6.1 information sources and quality	8,33	6.1.x	11 indicators	0,75	0,4	0,00	Y/N; cells dimension (mq)
		6.2 Information management practices & tools	8,33	6.2.x	6 indicators	1,40	0,7	0,00	Y/N
TOT	**100**	**13 factors**	**/**	**/**	**XX indicators**	**/**	**/**	**/**	**XX metrics**

*Table 1: Final structure of the CLIMABOROUGH impacts assessment and monitoring tool: capitals, factors, codification system, indicators related to factors and metrics. Application of the "traffic lights" assessment methodology (adapted from: Carmona, 2016). The "Green" score (good performance) results from Fv/Ni, whereas "Fv" is the Factor value and "Ni" is the Number of indicators; the "yellow" score corresponds to G*0,5, whereas "G" is the Green score; the value of the red score is always 0 and results from G*0, whereas "G" is the*

Green score. Some factors and indicators' values are still to be defined: the "xx" in the table stand for this gaps.

1.5 The concept of Climhubs and the two cities' challenges

As mentioned above, the evaluation and monitoring of the impacts of the CLIMABOROUGH project will be conducted in 4 pilot cities (Turin, Cascais, Grenoble and Differdange) selected among the 12 partner cities. The impacts assessment will be carried out across six capitals and two Climhubs.
In the previous section, the rationale behind the application of the capitals approach for the development of the KPIs-based assessment tool was extensively presented. Hereafter, we introduce the concept Climhubs, which constitutes a key-concept in the CLIMABOROUGH project.
The term "Climhubs" refers to the concept of "innovation hubs". These are experimental spaces where people with different perspectives and expertise work together on social and economic challenges. Innovation hubs are characterised by flexible and dynamic working methods and are often platform-based. They bring together academics, students and partners from different fields in order to test new solutions.
The hubs approach will support participating cities to define and deploy climate oriented, pathbreaking innovations – both on the technological and service side (i.e. content) and on the legal, administrative and spatial planning side (i.e. enabling conditions) – as defined by their Mission plans.
We have two thematic hubs, called CLIMHUBS. One focused on the transition "from waste to circularity", the second addressing the shift "from isolated energy and mobility systems to integrated services". Each of the 2 hubs includes 4 of the 8 leader cities and 2 of the remaining 4 cities that are "followers".
The "ClimHub" is more than a lighthouse pilot, in the sense that it promotes and actively works for a faster and more widespread diffusion of sustainable innovations against the climatic threats, leveraging on the evidence-based learning generated by co-creation dynamics seeing startup companies and solution providers involved on a peer basis with local public sector authorities in innovative replication methods. The Figure below synthetizes the allocation of the 8 CLIMABOROUGH leader cities to the two Climhubs.

Action/HUB	Description	City LEADER	City FOLLOWER
From isolated energy and mobility to integrated services	The need to rethink the way we live and we move in our everyday life comes from the evidence of the last years crises, that qualify the energy crisis in relation to: a) the need to differentiate and distribute the sources (and the geopolitical dependence they may create), b) the need to make clear and urgent choices towards less polluting sources for sustainable mobility and changes in mobility habits and housing. and c) the need to rethink the demand, that implies a radical rethinking of our socio-technical systems.	**Differdange Grenoble-Alpes Athens Sofia**	**Prijedor Pilsen Torino Maribor Cascais Ioannina**
From waste to circularity	Waste is a key in climate neutrality strategy. The shift from waste to 'resource recovery' requires both mindset and technological change. Cities offer a logical convening force for circulatity. Ideas, collaboration, value cases, and capacity building are vital aspects to address those	**Torino Maribor Cascais Ioannina**	**Katowice Krk Differdange Grenoble-Alpes Athens Sofia**

Figure 5: Leader cities and follower cities assigned to the two CLIMABOROUGH Climahubs.

1.6 The action plan and Action KPIs

Following the assessment of the state of urban metabolism, an action plan will be formulated, comprising the actions undertaken by cities to achieve climate neutrality. This plan encompasses the solutions executed within Climaborough, as well as other policies and strategic initiatives adopted by cities. To consider these efforts comprehensively, the Climate City Contracts devised within the NZC mission and other pertinent city documents will be reviewed.

Once an understanding of the implemented actions is established, they will be compared against the same set of urban metabolism indicators, now applied to monitor their implementation vis-à-vis the city's objectives. Actions will be evaluated based on the gaps identified through the urban metabolism analysis, thereby guiding further decision-making and adjustments to ensure progress towards climate neutrality.

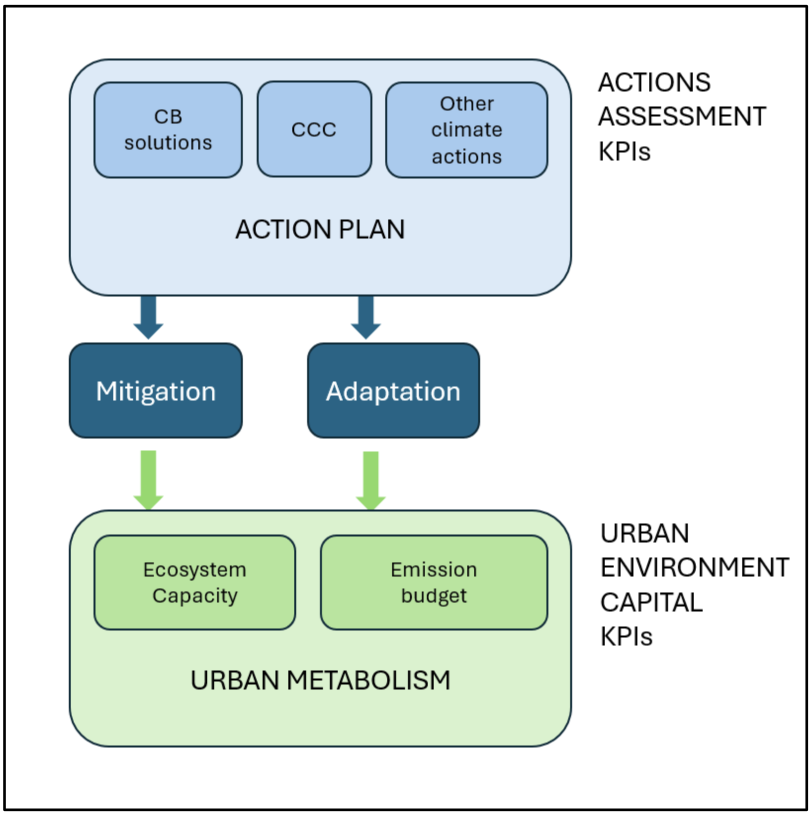

Figure 6: Relation between the Climate Urban Factors KPIs and Actions assessment KPIs within the Climate neutrality framework.

2. The sets of Key Performance Indicators: the six capitals

The summary of progress and advancements of CLIMABOROUGH foresees the identification of the project impacts across six capitals: the Urban environment capital, Social capital, Institutional capital, Policy capital, Financial capital and Information capital. Each capital was further broken down into different factors representing the most relevant aspects related to each capital; each factor was then combined with a set of indicators which enabled the performance measurement.
This system of capitals-factors-indicators-units was configured as shown in Table 1.
This section presents the six sets of KPIs related to the six capitals.

2.1 Urban environment capital

Urban environments are **dynamic and complex systems** shaped by interactions between natural and anthropic elements. The definition of "Urban environment capital" includes the intrinsic value of these elements, and encompasses both the capacity and the potential of the environment with respect to urban metabolism. In delineating the components of urban environment capital, two distinct dimensions emerge: eco-system capacity and system capacity.

Eco-system capacity pertains to the invaluable benefits derived from natural capitals, encompassing the role and functions of ecosystems within urban areas. These ecosystems, ranging from urban forests and wetlands to green spaces and water bodies, provide essential services such as air purification, water regulation, climate mitigation, and biodiversity conservation. Understanding and quantifying eco-system capacity is essential for assessing the contributions of urban ecosystems to cities' path to climate neutrality.

Conversely, **Emission Budget** delves into the baseline conditions of anthropic systems within urban environments, focusing on factors such as air, water, and soil pollutants. As cities continue to expand and urbanize, anthropogenic activities increasingly strain the environment, leading to pollution and degradation of natural resources. System capacity indicators provide crucial insights into the state of urban environmental health, monitoring key pollutants and their impacts on air quality, water quality, and soil health. By evaluating Emission Budget, urban planners and policymakers can identify areas of concern, prioritize interventions, and steer cities towards more sustainable and resilient pathways.

In this section we describe the Urban Environment Factors KPIs, which serve as a foundational framework for assessing the state of urban metabolism. As shown in Figure 6, in a second stage the "Action Assessment" KPIs will complement this analysis by evaluating the effectiveness of solutions implemented for the climate neutrality and including also the initiatives/solutions developed within the Climaborough project and (to be) outlined in the Climate City Contracts. By comparing these actions to the baseline established through the Climate Urban Factors KPIs, stakeholders can gauge their efficacy in advancing cities towards climate neutrality.
Importantly, the Action KPIs will not only focus on mitigation strategies but also address adaptation measures. As cities grapple with the impacts of climate change, it is essential to consider both aspects to ensure urban resilience and sustainability. By incorporating adaptation measures alongside mitigation efforts, cities can enhance their capacity to withstand climate-related challenges and thrive in a changing environment. This holistic approach underscores the interconnectedness of climate action and emphasizes the

importance of integrating both mitigation and adaptation strategies into urban planning and policy frameworks.

2.1.1 Emission Budget KPIs

Emission budget serves as a foundational framework for evaluating the state of cities in affecting climate. The assessment of capacity and the potential of the environment is a critical step in analyzing urban metabolism and addressing the complexity of urban anthropic systems.

In this section, we delve into the **structure of Emission Budget indicators**, which are designed to assess the health and resilience of urban environments across three primary dimensions: **air, water, and soil.** These indicators are organized to encompass a diverse range of **sub-factors**, ranging from energy production and waste management to specific emission sectors and pollution sources. Importantly, the assessment extends beyond greenhouse gas emissions to encompass other environmental features, including water and soil pollutants, reflecting a **systemic approach to the climate challenge**.

Through the **evaluation of Emission Budget indicators**, planners and policy makers gain valuable insights into the state of urban environmental health, identifying areas of concern and opportunities for intervention. In the following sections, we delve into the sub-factors and parameters addressing the complexities of system capacity assessment.

A) “Air” related indicators

Within the broader framework of system capacity, the **assessment of air quality** stands as a crucial dimension in evaluating the sustainability and resilience of urban environments towards climate challenges. The "Air" factor indicators encompass a diverse array of sub-factors, reflecting the multifaceted nature of air quality and its implications for human health, environmental integrity, and climate change mitigation efforts.

These indicators focus on **Energy Production (Energy Source)**, evaluating energy production sources and associated emissions to understand carbon intensity and air pollution; **Waste Management (Circular Economy)**, assessing waste management practices to minimize emissions and promote resource recovery; **Transport and Mobility**, examining transportation modes and emissions to promote sustainable mobility solutions and reduce air pollution; **Buildings Energy Consumption**, analyzing building energy use to improve efficiency and reduce emissions from operations; **AFOLU (Agriculture, Forestry, and Other Land Use)**, assessing land use practices to mitigate air pollution, enhance carbon sequestration, and protect ecosystem services.

The next paragraphs illustrate the comprehensive framework of indicators designed to identify and address sources of air pollution and greenhouse gas emissions in urban areas, promoting strategies to improve air quality, reduce emissions, and enhance climate resilience. The model is based on input informations which are translated to Air emissions: Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), F-gases (hydrofluoro carbons and perfluorocar bons), Sulphur hexafluoride (SF6), Nitrogen fluo (NF3), SO2, PM10, PM5, PM 2,5 and Ozone (O3).

Energy production: The sub-factor assesses the sources of energy generation within urban areas and their associated emissions. They include measures such as total energy production and the share of energy produced from various sources, including GPL, natural gas, diesel, gasoline, biofuel, wind, and solar. These indicators provide insights into the diversity of energy sources utilized in urban energy production, their contributions to overall energy supply, and their implications for carbon intensity and air pollution.

SUB-FACTORS	INPUT	OUTPUT
Energy production (Energy source)	Total energy used in the city (MWh/year) Share of energy produced through GPL Share of energy produced through Natural gas Share of energy produced through Diesel Share of energy produced through Gasoline Share of energy produced through Biofuel Share of energy produced through Wind Share of energy produced through Solar	Carbon Dioxide (CO2) tons/year Methane (CH4) Nitrous Oxide (N2O) F-gases (hydrofluoro carbons and perfluorocar bons) Sulphur hexafluoride (SF6) Nitrogen fluo (NF3) SO2 PM10 PM5 PM 2,5 Ozone (O3)

Table 2: The Urban environment capital KPIs. Energy production.

Waste management: The Waste Management indicators assess various aspects of waste collection, recycling, and disposal practices within urban areas. They include indicators such as the presence of systems for collecting materials like aluminum, glass, plastic, paper, electronic components, and textiles for recycling or reuse. Additionally, indicators measure the presence of internal municipal systems for recycling these materials.

Other indicators focus on the quantity of materials collected compared to the total produced, as well as the presence of facilities for waste treatment, such as incineration plants, and the methods used for disposing of unsorted waste, including incineration and landfilling. These indicators provide insights into the effectiveness of waste management practices, the promotion of recycling and reuse initiatives, and the sustainability of waste treatment processes within urban environments.

SUB-FACTORS	INPUT	OUTPUT
Waste management (Circular economy)	Presence of a system for collecting aluminium for recycling Presence of an internal municipal system for aluminium recycling Aluminium collected on the total produced Presence of a system for collecting glass for recycling Presence of an internal municipal system for glass recycling Glass collected on the total produced Presence of a system for collecting plastic for recycling Presence of an internal municipal system for plastic recycling Plastic collected on the total produced Presence of a system for collecting paper for recycling Presence of an internal municipal system for paper recycling Paper collected on the total produced Unsorted waste on the total produced Presence of an incineration plant Unsorted waste treated with incineration Unsorted waste treated with landfilling	Carbon Dioxide (CO_2) tons/year Methane (CH_4) Nitrous Oxide (N_2O) F-gases (hydrofluoro carbons and perfluorocar bons) Sulphur hexafluoride (SF_6) Nitrogen fluo (NF_3) SO_2 PM10 PM5 PM 2,5 Ozone (O_3)

Table 3: KPIs Urban environment capital KPIs. Waste management.

Transport and mobility: Within the sub-factor, indicators offer a comprehensive evaluation of urban transportation systems, covering private and public modes of transport as well as alternative mobility solutions. They include measures such as total energy use from private and public transport, the share of different fuels used in transportation, the prevalence of specific public transport modes, and the presence and utilization of shared mobility services like car-sharing and bike-sharing.

These indicators provide valuable insights into energy consumption patterns, mode choices, and the availability of sustainable transportation options within urban areas, supporting efforts to enhance sustainable transportation and reduce environmental impacts.

SUB-FACTORS	INPUT	OUTPUT
Transport and mobility	Total energy use from private transport Share of private transport running on GPL Share of private transport running on Natural Gas Share of private transport running on Diesel Share of private transport running on Gasoline Share of private transport running on Biofuel Share of private transport running on Hydrogen Share of private transport running on Electricity Total energy use from public transport Share of urban mobility under public transport Share of public transport running on GPL Share of public transport running on Natural Gas Share of public transport running on Diesel Share of public transport running on Gasoline Share of public transport running on Biofuel Share of public transport running on Hydrogen Share of public transport running on Electricity Share of urban mobility using public bus Presence of public tramway Share of urban mobility using public tramway Presence of underground Share of urban mobility using underground Presence of a car-sharing service Share of urban mobility using carsharing Share of urban mobility using bikes Presence of a bike-sharing service Share of urban mobility using shared bikes Presence of a e-roller/scooters sharing service Share of urban mobility e-roller/schooters	Carbon Dioxide (CO_2) tons/year Methane (CH_4) Nitrous Oxide (N_2O) F-gases (hydrofluoro carbons and perfluorocar bons) Sulphur hexafluoride (SF_6) Nitrogen fluo (NF_3) SO_2 PM10 PM5 PM 2,5 Ozone (O_3)

Table 4: The Urban environment capital KPIs. Transport and mobility

Buildings energy consumption: The Buildings Energy Consumption indicators provide a comprehensive assessment of energy usage and sources within both public and private buildings. They include measures such as total electricity consumption in public and private buildings, the proportion of electricity derived from renewable sources, and the energy consumed for heating purposes.

Additionally, the indicators assess the distribution of heating sources, including GPL, natural gas, diesel, gasoline, biofuel, and grid electricity, as well as the utilization of local renewable energy production for heating purposes. These indicators offer valuable insights into the energy efficiency and sustainability of building operations, guiding efforts to reduce energy consumption, increase renewable energy utilization, and promote environmentally friendly heating solutions within urban areas.

SUB-FACTORS	INPUT	OUTPUT
Buildings energy consumption	Total electricity use in public buildings (MWh/year) Share of electricity use in public building coming from renewable energy production Total energy use for heating in public buildings Share of public building heated through GPL Share of public building heated through Natural Gas Share of public building heated through Diesel Share of public building heated through Gasoline Share of public building heated through Biofuel Share of public building heated through grid electricity Share of public building heated electricity supplied through local renewable energy production Total electricity use in private buildings Share of electricity use in private building coming from renewable energy production Share of electricity use in private building coming from renewable energy production Share of private building heated through GPL Share of private building heated through Natural Gas Share of private building heated through Diesel Share of private building heated through Gasoline Share of private building heated through Biofuel Share of private building heated through grid electricity Share of private building heated electricity supplied through local renewable energy production	Carbon Dioxide (CO_2) tons/year Methane (CH_4) Nitrous Oxide (N_2O) F-gases (hydrofluoro carbons and perfluorocar bons) Sulphur hexafluoride (SF_6) Nitrogen fluo (NF_3) SO_2 PM10 PM5 PM 2,5 Ozone (O_3)

Table 5: The Urban environment capital KPIs. Buildings energy consumption.

AFOLU: The AFOLU (Agriculture, Forestry, and Other Land Use) sub-factor provides a comprehensive assessment of energy usage and production within the different urban land uses. The indicators encompass measures such as total energy consumption and production across various sources, including GPL, natural gas, diesel, gasoline, biofuel, wind, and solar energy.

These indicators offer insights into the energy dynamics and sustainability practices within agriculture, forestry, and land use activities, guiding efforts to promote energy efficiency, renewable energy adoption, and environmental conservation within these critical sectors.

SUB-FACTORS	INPUT	OUTPUT
AFOLU (Agricolture, Forestry and other land use)	Total energy use in AFOLU sectors Total energy produced through GPL Total energy produced through Natural Gas Total energy produced through Diesel Total energy produced through Gasoline Total energy produced through Biofuel Total energy produced through Wind Total energy produced through Solar Intensive farming waste Cattle farming Pigs farming	Carbon Dioxide (CO_2) tons/year Methane (CH_4) Nitrous Oxide (N_2O) F-gases (hydrofluoro carbons Sulphur hexafluoride (SF_6) Nitrogen fluo (NF_3) SO_2 PM10 PM5 PM 2,5 Ozone (O_3)

Table 6: Urban environment capital KPIs. Agriculture, Forestry and Other Land Use (AFOLU)

B) “Water” related indicators

The “Water” indicators encompass Water use; Wastewater and Rainwater runoff. Within the first domain the procapita use is assessed as per sector (residential, non-residential, industrial, agricultural and livestock). As for Waste water, the indicators relate to the load of substances and pollutants in the water after treatment: COD, N-NH4, N-NO3, P-tot, micropollutants and microplastics. Looking at the water runoff, both the Annual cumulative Stormwater runoff and the peak volume are taken into account.

Water Use: These sub-factor indicators offer a comprehensive assessment of water usage across various sectors within urban areas. These indicators encompass measures such as residential, non-residential (meaning tertiary sector), industrial, and agricultural/livestock use of groundwater, surface water, and recycled water. By evaluating per capita and per hectare usage, the indicators provide insights into the distribution and efficiency of water resources utilization within urban environments. This holistic approach enables cities to identify areas of high water consumption and promote sustainable water management practices.

SUB-FACTORS	INDICATORS RELATED TO FACTORS	UNITS
WATER USE	Residential use of groundwater pro capita	Total amount used (m3/year)
	Residential use of surface water pro capita	Total amount used (m3/year)
	Residential use of rainfall/reused water pro capita	Total amount used (m3/year)
	Non-residential use of groundwater pro capita	Total amount used (m3/year)
	Non-residential use of surface water pro capita	Total amount used (m3/year)
	Non-residential use of rainfall/reused water pro capita	Total amount used (m3/year)
	Industrial use of groundwater pro capita	Total amount used (m3/year)
	Industrial use of surface water pro capita	Total amount used (m3/year)
	Industrial use of recycled water (used in cycles)	Total amount used (m3/year)
	Agricultural use of groundwater per hectare	Total amount used (m3/year)
	Agricultural use of surface water per hectare	Total amount used (m3/year)
	Agricultural use of treated waste water (re-use) per hectare	Total amount used (m3/year)
	Livestock consumption of groundwater pro capita	Total amount used (m3/year)
	Livestock consumption of surface water pro capita	Total amount used (m3/year)
	Livestock consumption of treated waste water (re-use)	Total amount used (m3/year)

Table 7: The Urban environment capital KPIs. Water use

Waste water: The Wastewater indicators provide a comprehensive assessment of the quality and environmental impact of wastewater discharged into natural water bodies from various sources within urban areas. These indicators cover residential, non-residential, industrial, and agricultural/livestock activities, assessing parameters such as chemical oxygen demand (COD), nitrogen compounds (N-NH4, N-NO3), phosphorus (P-tot), micropollutants, and microplastics. By evaluating the loads of these contaminants released into natural water bodies, the indicators offer insights into the potential ecological risks and pollution levels associated with wastewater discharges. This comprehensive approach enables cities to identify priority areas for wastewater management and implement targeted measures to mitigate environmental impacts and safeguard water quality in urban ecosystems.

SUB-FACTORS	INDICATORS RELATED TO FACTORS	UNITS
WASTE WATER	COD load released into natural water bodies from residential use	Total COD load (ton/year)
	COD load released into natural water bodies from residential use	% Treated load/total generated load
	N-NH4 load released into natural water bodies from residential use	Total N-NH4 load (ton/year)
	N-NH4 load released into natural water bodies from residential use	% Treated load/total generated load
	N-NO3 load released into natural water bodies from residential use	Total N-NO3 load (ton/year)
	N-NO3 load released into natural water bodies from residential use	% Treated load/total generated load
	P-tot load released into natural water bodies from residential use	Total P-tot load (ton/year)
	P-tot load released into natural water bodies from residential use	% Treated load/total generated load
	micropollutants (load for some tracer compound e.g. carbamazepine) released ir	Total load (kg/year)
	micropollutants (load) released into natural water bodies from residential use	% Treated load/total generated load
	microplastics (load) reseased into natural water bodies from residential use	Total microplastics load (kg/year)
	microplastics (load) reseased into natural water bodies from residential use	% Treated load/total generated load
	COD load released into natural water bodies from non-residential use	Total COD load (ton/year)
	COD load released into natural water bodies from non-residential use	% Treated load/total generated load
	N-NH4 load released into natural water bodies from non-residential use	Total N-NH4 load (ton/year)
	N-NH4 load released into natural water bodies from non-residential use	% Treated load/total generated load
	N-NO3 load released into natural water bodies from non-residential use	Total N-NO3 load (ton/year)
	N-NO3 load released into natural water bodies from non-residential use	% Treated load/total generated load
	P-tot load released into natural water bodies from non-residential use	Total P-tot load (ton/year)
	P-tot load released into natural water bodies from non-residential use	% Treated load/total generated load
	micropollutants (load) released into natural water bodies from non-residential u	Total load (kg/year)
	micropollutants (load) released into natural water bodies from non-residential u	% Treated load/total generated load
	COD load released into natural water bodies from industrial use	Total COD load (ton/year)
	COD load released into natural water bodies from industrial use	% Treated load/total generated load
	N-NH4 load released into natural water bodies from industrial use	Total N-NH4 load (ton/year)
	N-NH4 load released into natural water bodies from industrial use	% Treated load/total generated load
	N-NO3 load released into natural water bodies from industrial use	Total N-NO3 load (ton/year)
	N-NO3 load released into natural water bodies from industrial use	% Treated load/total generated load
	P-tot load released into natural water bodies from industrial use	Total P-tot load (ton/year)
	P-tot load released into natural water bodies from industrial use	% Treated load/total generated load
	micropollutants (load) released into natural water bodies from industrial use	Total load (kg/year)
	micropollutants (load) released into natural water bodies from industrial use	% Treated load/total generated load
	microplastics (load) reseased into natural water bodies from industrial use	Total microplastics load (kg/year)
	microplastics (load) reseased into natural water bodies from industrial use	% Treated load/total generated load
	COD load released into natural water bodies from agricultural and livestock use	Total COD load (ton/year)
	COD load released into natural water bodies from agricultural and livestock use	% Treated load/total generated load
	N-NH4 load released into natural water bodies from agricultural and livestock us	Total N-NH4 load (ton/year)
	N-NH4 load released into natural water bodies from agricultural and livestock us	% Treated load/total generated load
	N-NO3 load released into natural water bodies from agricultural and livestock us	Total N-NO3 load (ton/year)
	N-NO3 load released into natural water bodies from agricultural and livestock us	% Treated load/total generated load
	P-tot load released into natural water bodies from agricultural and livestock use	Total P-tot load (ton/year)
	P-tot load released into natural water bodies from agricultural and livestock use	% Treated load/total generated load
	micropollutants (load) released into natural water bodies from agricultural and l	Total load (kg/year)
	micropollutants (load) released into natural water bodies from agricultural and l	% Treated load/total generated load
	microplastics (load) reseased into natural water bodies from agricultural and live	Total microplastics load (kg/year)
	microplastics (load) reseased into natural water bodies from agricultural and live	% Treated load/total generated load

Table 8: The Urban environment capital KPIs. Waste water

Rainwater runoff: The sub-factor encompasses critical metrics related to stormwater runoff and pollutant discharge into natural water bodies. These indicators include assessments of the annual cumulative volume of stormwater runoff and peak volumes, providing insights into water flow dynamics and flood risk management. Additionally, parameters such as chemical oxygen demand (COD), nitrogen compounds (N-NH4, N-NO3), phosphorus (P-tot), micropollutants, and microplastics are evaluated to understand the ecological impact of pollutant loads on natural water bodies. By monitoring these indicators, cities can effectively manage stormwater runoff and implement measures to mitigate pollution, preserving the quality of natural water ecosystems.

SUB-FACTORS	INDICATORS RELATED TO FACTORS	UNITS
RAIN WATER RUNOFF	Annual cumulative Stormwater runoff volume	Total amount (m3/year)
	Annual cumulative Stormwater runoff volume	% reteined/drained volume
	Stormwater runoff peak volume	Total amount (m3)
	Stormwater runoff peak volume	% reteined/drained volume
	COD load released into natural water bodies	Annual loads ton/year
	N-NH4 load released into natural water bodies	Annual loads ton/year
	N-NO3 load released into natural water bodies	Annual loads ton/year
	P-tot load released into natural water bodies	Annual loads ton/year
	Micropollutants (load) released into natural water bodies	Annual loads ton/year
	Microplastics (load) released into natural water bodies	Annual loads ton/year

Table 9: The Urban environment capital KPIs. Water Runoff

B) “Soil” factor indicators

Within the “Soil” factor, **different Land Uses** are taken into account, encompassing Residential, Industrial, Agricultural, Urban green areas, and Uncultivated areas with urban land use. These indicators provide a comprehensive assessment of land use and contamination within urban areas, monitoring the share of different land uses within urban borders.

SUB-FACTORS	INDICATORS RELATED TO FACTORS	UNITS
RESIDENTIAL LAND USE	Total residential land use	TOTAL Area (km2)
	Residential land use on total urban area	% area/municipality area
	Presence of contamination - soil and groundwater (e.g. brownfield)	% area/residential use area
	Presence of contamination only soil (e.g. brownfield)	% area/residential use area
	Sites under remediation	number of sites
	Remediation ongoing or concluded	Y/N
	Main contaminants	(e.g. PAH, chlorinated solvents, PFAS)
INDUSTRIAL LAND USE	Total industrial land use	TOTAL Area (km2)
	Industrial land use on total urban area	% area/municipality area
	Presence of contamination - soil and groundwater (e.g. brownfield)	% area/industrial use area
	Presence of contamination only soil (e.g. brownfield)	% area/industrial use area
	Sites under remediation	number of sites
	Remediation ongoing or concluded	Y/N
	Main contaminants	(e.g. PAH, chlorinated solvents, PFAS)
AGRICULTURAL LAND USE	Total agricultural land use	TOTAL Area (km2)
	Agricultural land use on total urban area	% area/municipality area
	Presence of contamination - soil and groundwater (e.g. brownfield)	% area/agricultural use area
	Presence of contamination only soil (e.g. brownfield)	% area/agricultural use area
	Sites under remediation	number of sites
	Remediation ongoing or concluded	Y/N
	Main contaminants	(e.g. PAH, chlorinated solvents, PFAS)
URBAN GREEN AREAS	Total urban green areas	TOTAL Area (km2)
	Urban green areas on total urban area	% area/municipality area
	Presence of contamination - soil and groundwater (e.g. brownfield)	% area/urban green areas
	Presence of contamination only soil (e.g. brownfield)	% area/urban green areas
	Sites under remediation	number of sites
	Remediation ongoing or concluded	Y/N
	Main contaminants	(e.g. PAH, chlorinated solvents, PFAS)
UNCULTIVATED AREAS WITH URBAN LAND USE	Total uncoltivated areas with urban land use	TOTAL Area (km2)
	Uncoltivated areas on total urban area	% area/municipality area
	Presence of contamination - soil and groundwater (e.g. brownfield)	% area/uncultivated areas
	Presence of contamination only soil (e.g. brownfield)	% area/uncultivated areas
	Sites under remediation	number of sites
	Remediation ongoing or concluded	Y/N
	Main contaminants	(e.g. PAH, chlorinated solvents, PFAS)

Table 10: The Urban environment capital KPIs. Land Use

Additionally, they evaluate the presence of **contamination in soil and groundwater**, including brownfield sites, and identify any sites under remediation. The indicators also track ongoing or concluded remediation efforts and the main contaminants present, such as PAH, chlorinated solvents, and PFAS. By monitoring these indicators, cities can effectively manage land use, identify areas requiring remediation, and mitigate the environmental impact of soil contamination on urban ecosystems.

2.1.1 Eco-system capacity KPIs

Urban ecosystems are dynamic and interconnected, encompassing a diverse array of habitats, green spaces, water bodies, and other ecological features. These ecosystems provide a multitude of ecosystem services (ES) that are essential for supporting human well-being and maintaining ecological balance. From regulating climate and purifying air and water to providing habitat for biodiversity and enhancing aesthetic values, urban ecosystems contribute to the overall functionality and resilience of cities.

The concept of **Eco-system capacity** underscores the importance of recognizing and valuing these ES, as well as understanding the factors that influence their provision and maintenance. By quantifying and mapping ES values, urban planners and policymakers can gain valuable insights into the benefits derived from urban ecosystems and the tradeoffs associated with different land use and development decisions. Moreover, integrating eco-system capacity considerations into urban planning processes can help prioritize conservation efforts, enhance green infrastructure, and promote sustainable development practices that support both human and ecological well-being.

In mapping eco-system capacity, we draw upon **sub-factors related to the mapping of five ES values** based on available data at city level by means of Integrated Evaluation of Ecosystem Services and Tradeoffs (InVEST) and i-Tree: EC1 Carbon Sequestration/Storage; EC2 Air Purification; EC3 Habitat Quality; EC4 Cooling Capacity; EC5 Water regulation (Urban Flood Risk Mitigation). The 5 factors (Table 11) present spatially explicit analysis, using maps as information sources and producing maps as outputs. The input-output indicators return results in biophysical terms (e.g., tons of carbon sequestered) with a flexible spatial resolution, allowing users to address questions at local, regional, or global scales. The models are based on production functions that define how changes in an ecosystem's structure and function are likely to affect the flows and values of ES across cities.

The Land Use/Land Cover (LULC) data were derived from the digital topographic dataset (BDTRE 2023) of the city freely available at Geoportale Piemonte. All the analyses were carried out using GIS software (ESRI ArchGIS Pro ver 3.2.2) and referred to the whole city level.

SUB-FACTOR	INPUT	OUTPUT
1.1 EC1 Carbon Sequestration/Storage	Amount of carbon stored in 4 different carbon pools Amount of sequestered carbon over time	Raster showing the amount of carbon stored in each pixel for the current, future, and scenarios. It is a sum of all of the carbon pools provided by the biophysical table. Units are metric tons per pixel Rasters showing the difference in carbon stored between the future landscape and the current landscape. The values are in metric tons per pixel
1.2 EC2 Air Purification	Species (Identify and record the species and genus names of each tree assessed) Diameter at breast height - DBH (Measure and record the tree stem diameter at breast height for each tree) Total tree height (Height from the ground to the top (alive or dead) of the tree)	SO2 removed annually NO2 removed annually PM2.5 removed annually O3 removed annually CO removed annually
1.3 EC3 Habitat Quality	Land Use/Land Cover Anthropic threats (LULC) Sensitivity of each land use to anthropic threats	Extent of habitat quality Habitat degradation
1.4 EC4 Cooling Capacity	Land Use/Land CoverShade (%) Evapotranspiration (mm) Albedo (K) Air temperature (°C) Quantity and quality of urban green areas (Ha) Imperviousness Building intensity (K)	Average Cooling Capacity value (K) Average temperature value (degC). Average temperature anomaly (degC).
1.5 EC5 Water regulation (Urban Flood Risk Mitigation)	Watershed vector delineating areas of interest Land Use/Land CoverMap of soil hydrologic groups (USGS soil groups) Map of average annual precipitation. (10 years) Stormwater runoff and percolation coefficients for each Soil group (CN K)	mean_retention_ratio (%) total_retention_volume (m3/year) mean_runoff_ratio (%) total_runoff_volume (m3/year) mean_percolation_ratio (%) total_percolation_volume (m3/year)

Table 11: The Urban environment capital KPIs. Ecosystem capacity.

EC1 Carbon Storage: The Carbon Storage model focuses specifically on quantifying the amount of carbon stored in vegetation and soils within a given landscape. It utilizes various data inputs such as land cover, vegetation types, soil types, and climate data to estimate carbon storage in different pools, including aboveground biomass, belowground biomass, and soil organic carbon. By conducting spatial analysis, the model generates maps and tabular outputs that supports efforts to prioritize conservation and restoration actions for climate change mitigation.

EC2 Air purification: EC2 is based on the I-Tree Eco model, which uses tree data (derived by urban tree cadaster) to estimate ecosystem services provided by urban or rural forests using biophysical information in the structure and composition of trees. The software allows to estimate the urban forest structure and its function on air pollutant removal.

EC3 Habitat quality: the INVEST Habitat Quality model combines information on LULCs and biodiversity threats to create habitat quality maps. This approach produces two main sets of information that are useful for making an initial assessment of conservation needs:

the relative size and degradation of different habitat types in an area, and changes over time. This approach also allows rapid assessment of habitat status and trends as a proxy for more detailed measurements of biodiversity status.

EC4 Cooling capacity: based on the INVEST Urban Cooling model, the indicator identifies the contribution of vegetation in reducing urban temperatures, which is crucial for enhancing urban resilience against climate-induced temperature increases. The model calculates an index of heat mitigation based on shade, evapotranspiration, and albedo, as well as distance from cooling islands (e.g. parks). The index is used to estimate a temperature reduction by vegetation. Finally, the model estimates the value of the heat mitigation service using two (optional) valuation methods: energy consumption and work productivity.

EC5 Water regulation: the urban flood risk mitigation INVEST model addresses cloudburst impacts, particularly in densely populated hillside cities. It calculates the runoff reduction, i.e. the amount of runoff retained per pixel compared to the storm volume, based on land cover, soil type, and rainfall data. Key inputs include watershed delineation, rainfall depth, land use/cover maps, soil hydrologic groups, and biophysical values for land classes. The model integrates various datasets, including imperviousness levels and tree cover density, to classify urban areas and assess their vulnerability to flooding, aiming to inform urban planning and mitigation strategies.

2.2 Social capital

The social capital examines the impacts of CLIMABOROUGH projects on local communities and societal well-being. This includes aspects such as social cohesion, health outcomes, equity, and community resilience. Progress in this area may involve enhanced community engagement, improved access to services, and the empowerment of marginalized groups.

Table 12 summarises the relevant factors related to social capital and the indicators that are relevant for the CLIMABOROUGH project impact assessment.

CAPITALS	FACTORS	CODE	INDICATORS RELATED TO FACTORS	METRICS (*please*	THRESHOLDS
2. SOCIAL CAPITAL	2.1 Participation	2.1.a	Presence of a local government climate-related participatory strategy or plan	Y/N	/
		2.1.b	Presence of city programmes/projects/networks that engage citizens in climate change response	Y/N	/
		2.1.c	Establishment of climate-related networks and partnerships with other cities	Y/N	/
		2.1.d	Establishment of climate-related partnerships with research centers/academia	Y/N	/
		2.1.e	Presence of climate-related networks involving the private sector	Y/N	/
		2.1.f	Presence of volunteer citizens programs related to climate issues/emergencies	Y/N	/
		2.1.g	Nomination/participation in climate-related awards or competitions	Y/N	/
		2.1.h	Participation to European R&I projects relevant to climate change mitigation	Y/N	/
		2.1.i	Organization by the local government of deliberative *(where you decide/vote)* events on climate-related issues open to citizens	Y/N Frequency	1-4 times/year; 5-9 times/year; +10 times/year
		2.1.l	Organization by the local government of activities for participatory budgeting for citizens	Y/N	/
		2.1.m	Organization by citizens of demonstrations and strikes for climate-related issues	Y/N Frequency	Never; Weekly; Monthly; Yearly
		2.1.n	Implementation of citizens participation monitoring processes (e.g. internal or external audits)	Y/N	/
	2.2 Communication and knowledge	2.2.a	Regular disclosure on climate actions implementation and the progress towards achieving climate targets (publication of reports on the institutional website)	Y/N Frequency	Never; Weekly; Monthly; Yearly
		2.2.b	Discussion of climate-related issues on the local media	Y/N Frequency	Daily; Weekly; Monthly; Yearly
		2.2.c	Organization of public campaigns on climate-related issues at the local level	Y/N Frequency	Monthly; Yearly
		2.2.d	Organization of educational activities (capacity-building courses, trainings, awareness campaigns, etc.) for citizens	Y/N	/
		2.2.e	Organization of educational activities for specific target groups: women and socially excluded groups	Y/N	/
		2.2.f	Partnerships with schools and other training institutions for the organization of educational activities (capacity-building courses, trainings, awareness campaigns, etc.) for young generations	Y/N	/
		2.2.g	Organization of citizen science initiatives (phenomena monitoring, data collection, etc.)	Y/N	/
	2.3 Rules and norms of society	2.3.a	Existence of informal boards/groups resulting from cultural-historic development	Y/N	/
		2.3.b	Solidarity in society: amount of donations given from the society/the local government to most climate impacted social groups	€	
		2.3.c	Availability of volunteer organizations/registers to activate in case of weather extremes and climate-related emergencies	Y/N	/

Table 12: CLIMABOROUGH assessment KPIs. The Social capital..

The Social capital focuses on relationships between multiple stakeholders, shared norms and values that qualify a certain society. It contributes much to the capacity of local governments to implement effective climate measures and achieve climate neutrality, as well as on the well-being level of citizens. It can be described and quantified by indicators referred to three Social capital factors:

- Participation: is the "ability to join a governance process and to act within it" (Máñez et al., 2014). Integrating heterogeneous stakeholders from multiple sectors in this process should be intended as a fundamental step in climate neutrality governance, since it guarantees the success of comprehensive participation processes. The set of indicators linked to participation take into account different possible forms of collaboration to involve in climate neutrality-related planning and implementation activities both private businesses, citizens and other institutional and non-institutional partners: these are networks, working groups, series of meetings, deliberative events, volunteer programs, participatory budgeting activities, demonstrations and strikes, and others;
- Communication and knowledge: knowledge at the society level is closely related to past societal and natural experiences as well as to the particular cultural and historical context. The higher is citizens' and other stakeholders' knowledge level about climate risks and possible options to tackle them (adaptation and mitigation), the higher is the capacity of individuals and the entire society to increase their resilience. Education can play an important role in raising collective knowledge. The ALLEA 2020 Report highlighted the beneficial impacts of education initiatives across Europe having as targets primary, secondary and higher level education. Education has been recognised as a key premise for climate change awareness, mitigation and adaptation. Thus, "a strong emphasis should be placed on strengthening the environmental awareness of the young generation through education and other forms of youth engagement" (Darren, 2021).
  Effective communication strategies and competences are required to improve knowledge among all stakeholders and to implement successful governance processes. Publication of periodic reports, frequent discussion of climate-related issues on the local media presence of citizens committees, awareness campaigns, trainings, forums, capacity-building courses in schools are all good options to increase knowledge and, consequently, to boost climate neutrality achievement;
- Rules and norms of society: informal rules and norms in a society mainly come from historical background and cultural context and are relevant factors in the success of climate neutrality governance processes: solidarity, cooperation, donations and volunteering initiatives are all adequate indicators of the informal norms characterizing one specific social context.

2.3 Institutional capital

The Institutional capital evaluates the effectiveness of governance structures and institutional arrangements in facilitating CLIMABOROUGH initiatives. This includes assessing the capacity for decision-making, coordination mechanisms, and stakeholder engagement processes. Progress may involve the establishment of effective partnerships, transparent governance practices, and the adoption of inclusive decision-making processes.

Table 13 Summarises the factors that are relevant to evaluate the institutional capital and highlights the indicators for the CLIMABOROUGH project impact assessment.

CAPITALS	FACTORS	CODE	INDICATORS RELATED TO FACTORS	METRICS (please	THRESHOLDS
3.INSTITUTIONAL CAPITAL	3.1 Organizational structure	3.1.a	Breakdown of responsabilities and tasks related to climate neutrality management into multiple departments/groups/divisions constitutes a primary barrier to climate objectives achievement	Y/N	/
		3.1.b	Presence of a department/division/group 100% dedicated to climate management, with specific responsabilities and competences	Y/N	/
		3.1.c	Presence of a department/division/group 100% dedicated to climate neutrality management, with specific responsabilities and competences	Y/N	/
		3.1.d	Inter-departmental coordination for multi-level governance: organization of regular alignment-meetings, presence of interdepartmental working groups	Y/N	/
		3.1.e	Territorial coordination for multi-level governance: organization of regular alignment-meetings, presence of territorial working groups, networks at the territorial/regional level	Y/N	/
	3.2 Skills and competences	3.2.a	Average level of education of local government's employees (or collaborators) responsible for climate-related issues	High school; university studies; more	/
		3.2.b	Adequacy of the background studies of local government employees (or collaborators) to manage climate-related issues	High; Medium; Low	/
		3.2.c	Local government's employees have received training on climate-related issues	Y/N	/
		3.2.d	Presence in most of the local government's departments of at least one nominated focal person for climate management	Y/N	/
		3.2.e	Membership of local government's employees in non-governmental and governmental technical aid organisations (fire brigade, red cross, THW, etc)	%	% of the total number of employees +66%; +33% ; -33%
		3.2.f	Presence of a figure (Resilience officier; Climate manager; etc.) with specific competences and skills for climate neutrality management in the local government	Y/N	/
		3.2.g	Establishment of climate change research centres within universities or other institutions	Y/N	/
		3.2.h	Establishment of external linkages/networks with research institutions (within country, within sub-regions, within Europe and/or globally)	Y/N	/
	3.3 Transparency and trust in political actions	3.3.a	Level of (perceived) prioritization of climate action by local government	High; Medium; Low	/
		3.3.b	Percentage of population taking part in municipal elections on average (last 5 years)	n° of people	popolutation 66% +33% -33%
		3.3.c	Duration of the local government mandate	n° of years	4
		3.3.d	Presence of climate-realted issues in the election programm of the last-elected political parties (local government)	Y/N	/
		3.3.e	Periodic statistical surveys published reflecting the opinions of the population in regards to local government's performed work	Y/N	/
		3.3.f	Organization of periodic formal meetings with stakeholders who are involved in continuous networking processes	n° of meetings/year	1-4 times/year; 5-9 times/year; +10 times/year
		3.3.g	Presence of comprehensive anti-corruption policies	Y/N	/
		3.3.h	Presence of laws/declarations, etc. in order to provide legal basis for the freedom of media	Y/N	/
		3.3.i	Periodic submission of new laws or decrees in a public document and/or publication on the institutional website	Y/N	/

Table 13: KPIs for the CLIMABOROUGH project impacts assessment. The Institutional capital.

The term “institution” here refers to “the rules and customs of a special group of similar interest” (Máñez et al., 2014), whereas the common interest is achieving climate neutrality. Máñez et al. (2014) mention the principle of “institutional fitness”. The complexity of the institutional capital can be interpreted and managed by distinguishing three factors:

- Organizational structure: enlightening, representing and assessing the organizational structure of public administration entities such as local governments is particularly challenging since these are characterized by a high grade of hierarchy and bureaucracy and are not “single, monolithic entities” (Aubry et al., 2014). In fact, public administration institutions are often split into multiple organizations, agencies, departments, divisions. Nevertheless, studying in detail local governments’ organizational structure allows an in-deep understanding of internal processes and enable the detection of gaps and criticalities that lie in communication, coordination, control. Andrews (2010) claims that organizational structures “provide the pervasive foundation for achieving coordination and control within an organization” and that they have a significant impact on the fulfilment of objectives, placing emphasis on the relationship between structure and performance. In the case of Climate neutrality achievement, it is of outmost importance assessing local governments’ organizational structures to correlate it with the typical lack of coordination and communication between different departments, which constitutes a primary barrier to the effective implementation and efficient management of climate measures.
  The indicators applied to measure the performance of local governments’ organizational structures are the distribution of responsibilities and tasks related to climate management into multiple departments, the organization of regular alignment-meetings or other initiatives aimed at guaranteeing inter-departmental and territorial coordination;
- Skills and competences: this factor commonly refers to individual skills and competences. In the case of local governments, the human capital results from the sum of employees’ and collaborators’ skills and competences. It can be measured by assessing the average level of education of local government’s employees and the adequacy of employees’ background studies to manage climate-related issues, as well as the distribution of these competences in the different departments/working groups/divisions: do every departments have assigned at least one nominated focal person for climate issues management? Have some staff in every departments received specific training on climate related-issues? How many local government’s employees are members of technical aid organizations such as fire brigades, red cross, Civil Protection, etc.?
  Skills and competences can be gathered from formal or informal learning. Skills, knowledge and experiences are closely connected to risk awareness and preparedness ((Máñez et al., 2014);
- Transparency and trust in political actions: the latest released European Social Survey[2] (2020) reports that “trust helps to sustain a cooperative social environment, to facilitate collective behaviour and to encourage a regard for the public interest”. Measuring trust in political actions requires the adoption of heterogeneous indicators referred to the level of citizens’ perceived prioritization of the climate

2 https://ess-search.nsd.no/en/study/172ac431-2a06-41df-9dab-c1fd8f3877e7

issue by the local government, the percentage of population expressing a vote in political elections, the duration of the government's mandate; the level of transparency in political actions is measurable on the basis of the publication of periodic statistical surveys reflecting the opinions of the population in regards to government's performed work, the presence of anti-corruption policies, the presence of laws and guidelines that provide a legal basis for the freedom of media, the periodic submission of newly approved laws or decrees in a public document.

2.4 Policy capital

The policy capital focuses on the development and implementation of policies and regulations to support CLIMABOROUGH goals. This includes assessing the alignment of policies with sustainability objectives, the effectiveness of regulatory frameworks, and the integration of climate considerations into policy-making processes. Progress may involve the adoption of climate-resilient policies, the enforcement of environmental regulations, and the promotion of sustainable development agendas.
Table 14 Summarises the indicators that are relevant to evaluate the CLIMABOROUGH project impact assessment in relation to policies.

CAPITALS	FACTORS	CODE	INDICATORS RELATED TO FACTORS	METRICS (please	THRESHOLDS
4. POLICY	4.1 Regulatory framework	4.1.a	Adoption of local mitigation plan and last update	Y/N	within the last 2 year; between 2-5 years ago; more than 5 years ago
		4.1.b	Adoption of local adaptation plan and last update	Y/N	within the last 2 year; between 2-5 years ago; more than 5 years ago
		4.1.c	Adoption of local joint mitigation-adaptation plan (Climate neutrality plan) and last update	Y/N	within the last 2 year; between 2-5 years ago; more than 5 years ago
		4.1.d	Presence of cross-sectoral mitigation plans	Y/N	/
		4.1.e	Presence of cross-sectoral adaptation plans	Y/N	/
		4.1.f	Presence of sector-specific mitigation plans	Y/N	/
		4.1.g	Presence of sector-specific adaptation plans	Y/N	/
		4.1.h	Adoption of climate emergency plans and last update	Y/N	within the last 2 year; between 2-5 years ago; more than 5 years ago
		4.1.i	Permanency of climate related plans/laws/regulations (time period): update frequency	Frequency	1-2 years; 3-5 years; more than 5 years
		4.1.l	Compulsory nature of the climate plans/law/regulations	Y/N	/
		4.1.m	Compulsory nature of the climate adaptation plans/law/regulations	Y/N	/
		4.1.n	Plans quality: integration of available climate services (climate projections/models, vulnerability assessment, risk assessments, cost-benefits analysis, etc.) into climate plans	Y/N	/
		4.1.o	Plans quality: involvement of experts (external consultants/collaborators) for climate plans redaction	Y/N	/
		4.1.p	Co-development of climate plans with stakeholders (citizens, private businesses, NGOs) trhough participatory processes	Y/N	/
		4.1.q	Inclusion of detailed stakeholders identification, budget, implementation and monitoring procedures, other details in the climate plans	Y/N	/
		4.1.r	Implementation of monitoring procedures: regular monitoring and reporting on the application of the climate plans/laws/regulations	Y/N	/

Table 14: KPIs for the CLIMABOROUGH project impacts assessment. The Policy capital.

- Regulatory framework: the regulatory framework of climate neutrality includes every type of urban planning, mitigation, adaptation and emergency laws, norms, strategies and plans. These regulatory tools can be cross-sectoral, sector-specific, hazard-specific, target-specific and can have a compulsory nature or a non-compulsory nature. Some aspects are of primary importance in order to assess and measure a local government's climate neutrality governance performance: the update level of the regulatory documents, their permanency, the figures responsible for their redaction, the possible involvement of experts in the redaction process (consultants, collaborators) and of citizens communities through participatory processes (co-development). Furthermore, the inclusion in these tools of indications and guidelines on monitoring procedures and the actual implementation of regular and frequent monitoring activities of their impacts is an aspect that makes the difference in climate governance performance.

2.5 Financial capital

The financial capital evaluates the financial implications of CLIMABOROUGH interventions. This includes assessing economic growth, job creation, resource efficiency, and the promotion of sustainable business practices. Progress may be measured by increases in economic productivity, investments in green technologies, and the creation of green jobs. Table 15 summarises the factors related to the financial capital and the indicators for the CLIMABOROUGH project impact assessment.

CAPITALS	FACTORS	CODE	INDICATORS RELATED TO FACTORS	METRICS (*please*	THRESHOLDS
5. FINANCIAL CAPITAL	5.1 Climate finance	5.1.a	Presence of a local investment strategy (budgeting) for the implementation of the current climate plans or climate actions	**Y**/N	/
		5.1.b	Main sources activated by the local government to obtain funds to tackle climate change	%	Public (regional): %40__ Public (national:% 60__ Public (international): %__ Private: %___
		5.1.c	Presence of a specific person/group 100% dedicated to search and management of funds to tackle climate change within the local government	Y/N	/
		5.1.d	Application to climate-realated European funding programmes within the last 5 years	Y/N	/
		5.1.e	Application to non-European funding programmes relevant to climate change within the last 5 years	Y/N	/
	5.2 Disaster funds/ Compensation of losses	5.2.a	Availability of governmental disaster compensation funds	Y/N	/
		5.2.b	Ratio of public and private investments on disaster funding	%	Public: 50%__ Private: 50%___
		5.2.c	Total yearly amount of expenses (percentage of the local GDP) on disaster funding	%	GDP +50%; -50%; +25%; -25%
		5.2.d	Adquisition of an insurance coverage specific for climate-related losses by the local government and date of adquisition	Y/N Date:__/__/___ –	/
		5.2.e	Insurance ceiling of the local government's insurance coverage for climate-related losses	€	?
		5.2.f	Presence of obligation for privates to adquire an insurance insurance coverage specific for climate-related losses	Y/N	/
		5.2.g	Percentage of households having insurance related to specific climate-related issues	%	**66**%; +33%; -33%
		5.2.h	Percentage of enterprises having insurance related to specific climate-related issues	%	**66**%; +33%; -33%
		5.2.i	Percentage of damages that were covered by insurances during the last extreme events	%	66%; +33%; -33%

Table 15: KPIs for the CLIMABOROUGH project impacts assessment. The Financial capital.

Financial capital corresponds to the most common meaning of the term “capital”. It refers to tangible resources and involves all types of wealth (funds, substitutions, compensations etc.) that are provided to local governments by banking industries, private businesses or by means of public funding programs at the international, European, national or regional scale. Financial capital enables both medium and long term investments in climate neutrality and immediate reactions to climate extremes or *ex-post* compensations.

- Climate finance: the availability of resources for climate finance (financing the implementation of measures aimed at reducing CO2 emission and/or at increasing resilience) and their sources are assessed and measured by a dedicated set of indicators;
- Disaster funds and different loss compensation instruments are the second factor of financial capital. Assessing this aspect of climate neutrality governance basically consists in investigating what is the ratio of public and private investments on disaster funding and what is the total amount of the budget devoted to disaster expenses. Insurances are important sources of losses compensation: insurance policies are the most common compensation instrument. Furthermore. as argued by Bernardini et al. (2023), insurance brokers can play an important role in supporting cities in climate change impacts mitigation not only by providing convenient and adequate insurance products but also – and here lies the innovation – by providing information and advisory to design and implement climate adaptation measures (ex-ante) thanks to their access to valuable disaster-related information.

2.6 Information capital

This newly introduced capital is closely linked to information management, tools and procedures and it is indeed seen as one of the pillars of climate neutrality strategies. An optimal exploitation and interpolation of the available climate and non-climate information enables informed decisions in complex anthropic systems. Despite the growing availability of data and of climate data, a general lack of actionable information is still characterizing urban decision-making processes. This topic hence deserves particular attention in the context of cities' transition towards climate neutrality.
Table 16 Summarises the factors that define the information capital and the indicators that are relevant for the CLIMABOROUGH project impact assessment.

The attention of governments is actually being increasingly driven to the issue of climate information management: the United States of America, for example, recognized that up to one third of its gross domestic product depends on accurate weather and climate information (Brasseur et al., 2016).

CAPITALS	FACTORS	CODE	INDICATORS RELATED TO FACTORS	METRICS (please	THRESHOLDS
6. INFORMATION CAPITAL	6.1 Information sources and quality	6.1.a	Local climate information sources: the local government acquires information from online portals only	Y/N	/
		6.1.b	Local climate information sources: the local government contracted/established a partnership with specialized climate services* provider/s	Y/N	/
		6.1.c	Local climate information sources: collaboration/ establishment of partnerships with other stakeholders to collect data on climate-related issues	Y/N	/
		6.1.d	Local climate information sources: the local government contracted specialized consultants for climate information interpretation/elaboration	Y/N	/
		6.1.e	Resolution of the available climate information at the local scale	cells dimension (mq)	?
		6.1.f	Performance/acquisition of climate vulnerability assessments at the local scale	Y/N	/
		6.1.g	Performance/acquisition of climate economic impacts assessments at the local scale	Y/N	/
		6.1.h	Level of disaggregation of the available climate information at the local scale: acquisition of information on climate vulnerability and impacts on specific sectors/economic activities	Y/N	/
		6.1.i	Level of disaggregation of the available climate information at the local scale: acquisition of information on climate impacts on specific target groups (women and/or socially excluded groups)	Y/N	/
		6.1.l	Level of differentiation by user of the available climate services: user-driven climate services	Y/N	/
		6.1.m	Acquisition of visulation tools: climate maps, infographic products, etc.	Y/N	/
		6.1.n	Acquisition/translation of climate services products (informative material: factsheets, reports, etc.) into the local language	Y/N	/
		6.1.o	Availability of urban sensors providing real-time climate monitoring data	Y/N	/
	6.2 Information management practices & tools	6.2.a	Presence of local government's guidelines, policies, plans, obligations, standards for climate information management	Y/N	/
		6.2.b	Presence of local government's specific guidelines for the interoperability between climate-related databases and information systems	Y/N	/
		6.2.c	Accessibility of local climate information for citizens: availability of a dedicated section into local government's website	Y/N	/
		6.2.d	Accessibility of local climate information for citizens: availability of a governmental Opensource central portal/platform housing all relevant local climate information	Y/N	/
		6.2.e	Availabilty of governmental dedicated apps for climate emergency management (alerts, early warnings, etc.)	Y/N	/
		6.2.f	Availability of dedicated tools/apps for climate-related parameters monitoring by citizens (citizen science, participatory data collection)	Y/N	/

Table 16: KPIs for the CLIMABOROUGH project impacts assessment. The Information capital

Information management processes related to climate change management are affected by numerous and serious shortcomings. Hence, there is much room for improvement. In order to achieve optimization it is necessary to operate on different levels at the same time. In the proposed Climate neutrality governance assessment framework, two levels (two factors) of Information capital are taken into consideration:

- Information availability and quality: this factor refers to climate and non-climate information sources, resolution, level of detail, level of disaggregation and differentiation and availability of information visualization tools. Local governments acquire information from various sources which are more or less reliable and in some cases even contract specialized consultants to be supported in information interpretation and application;

- Information management practices and tools: the indicators measuring this factor are linked to three interconnected levels: the regulatory level (guidelines, policies, plans, obligations, standards on climate information management), the administrative level (local government's information management operations), the technical level (presence of sensors for the acquisition of urban real-time data, interoperability between databases).

Both these two factors composing the Information capital have great impacts on the adequacy and fitness of cities' governance in view of their transition towards Climate neutrality.

3. Testing and co-design the CLIMABOROUGH assessment and monitoring tool

3.1 The application of the Governance (self-) assessment tool - The city of Krk

Assessing climate neutrality governance – or governance in general, even applied to other common goals – is a greatly demanding task. Composite indicators allow to compile and grasp at a glance large amounts of information related to many different and interrelated governance dimensions in a single score for each assessed governmental entity or organization.
The design of good (valid and reliable) metrics required the design and adoption of robust methodologies.
A first test of the sets of KPIs related to the aspect of Climate neutrality governance was conducted in the city of Krk, a CLIMABOROUGH follower city, in August 2023.
The City of Krk, with its 6.200 inhabitants, is an its self-governing city and an island. Islands are on the verge of major changes.
The local government put much effort in performing tasks of local importance that directly meet the needs of citizens and which are not assigned by the Constitution or law to state bodies. Tasks that are complementary to project activities are:
i) settlement and housing;
ii) space and urbanism;
iii) utilities;
iv) protection and improvement natural environment; and
v) other activities in accordance with special laws.
Krk is part of the CLIMABOUROUGH Climhub1: “From isolated energy and mobility to integrated services”. The future of the Krk island is based on development strategies for the use of renewable energy sources.
Hereafter, the fillable tables submitted to the city of Krk’s representatives. The column “notes” reports the comments added by the persons in charge of providing the required information.

Country	Croatia
City	Krk
Population	6.450 inhabitants
Landscape	Sea/Island/Mediterranean
Climaborough Climate HUB	From isolated energy and mobility to integrated services
Current membership in climate-related networks	Covenant of Mayors (2009)
Current partnerships in climate-realated funding programmes/projects	Climaborough (2023); Innoplastic (2020)
Obtained climate-related awards	Small cities: <10000 inhabitants: Smart city of the year in Croatia (2022); Ecocity of Croatia (2021); Best liveable city (2019-2022); Best economic managament in Croatia (2019-2022); Best social politics in Croatia (2019-2022)

Table 17: Data on the city of Krk

CAPITALS	FACTORS	CODE	INDICATORS RELATED TO FACTORS	METRICS	THRESHOLDS	NOTES
2. SOCIAL CAPITAL	2.1 Participation	2.1.a	Presence of a local government climate-related participatory strategy or plan	Y/N	/	
		2.1.b	Presence of city programmes/projects/networks that engage citizens in climate change response	Y/N	/	Water suply shared and refined (2021), sewage adapted (2017-2022), optical network (2021-2023), power plants, wind power plants in preparation (state laws has to be changed, working on it). Shared cars in public firms, electric cars, electric power plants (shared), electric motors, scooters, bikes system for whole island (7 municipalities). Eco networks (social networks)
		2.1.c	Establishment of climate-related networks and parternships with other cities	Y/N	/	Networks with other cities in Krk island (7 cities) through the shared public comunal society; smart city waste-water-energy-sewage, smart city firm, eco firm. On the regional level we have 2 networks, one is for rural development and eco and the other is for sea eco and fishermans network
		2.1.d	Establishment of climate-related partnerships with research centers/academia	Y/N	/	University of Rijeka; thorugh EU projects…
		2.1.e	Presence of climate-related networks involving the private sector	Y/N	/	
		2.1.f	Presence of volunteer citizens programs related to climate issues/emergencies	Y/N	/	Volunteer civil protection; Civil service; 2 NGOs: Eco Kvarner, Moj otok
		2.1.g	Nomination/participation in climate-related awards or competitions	Y/N	/	Smart city of the year in Croatia (2022); Best social politics in Croatia (2019-2022); Ecocity of Croatia (2021); Best social politics in Croatia (2019-2022)
		2.1.h	Participation to European R&I projects relevant to climate change mitigation	Y/N	/	Climaborough (2023); Interreg (Innoplastic, 2020)
		2.1.i	Organization by the local government of deliberative *(where you decide/vote)* events on climate-related issues open to citizens	Y/N	1-4times/year; 5-9times/year; +10times/year	
		2.1.l	Organization by the local government of activities for participatory budgeting for citizens	Y/N	/	Board for environmental protection: city councils involving citizens and politicians for negotiation
		2.1.m	Organization by citizens of demonstrations and strikes for climate-related issues	Y/N Frequency	Never; Weekly; Monthly; Yearly	NGOs (Eko Kvarner) and local government organized a demonstration for limiting the enviornmental impact of LNG plant on the island of Krk (2017)
		2.1.n	Implementation of citizens participation monitoring processes (e.g. internal or external audits)	Y/N	/	
	2.2 Communication and knowledge	2.2.a	Regular disclosure on climate actions implementation and the progress towards achieving climate targets (publication of reports on the institutional website)	Y/N Frequency	Never; Weekly; Monthly; Yearly	
		2.2.b	Discussion of climate-related issues on the local media	Y/N Frequency	Daily; Weekly; Monthly; Yearly	
		2.2.c	Organization of public campaigns on climate-related issues at the local level	Y/N Frequency	Monthly; Yearly	On waste management, water management…
		2.2.d	Organization of educational activities (capacity-building courses, trainings, awareness campaigns, etc.) for citizens	Y/N	/	In previous years especially
		2.2.e	Organization of educational activities for specific target groups: women and socially excluded groups	Y/N	/	
		2.2.f	Partnerships with schools and other training institutions for the organization of educational activities (capacity-building courses, trainings, awareness campaigns, etc) for young generations	Y/N	/	Comics, courses, videos
		2.2.g	Organization of citizen science initiatives (phenomena monitoring, data collection, etc.)	Y/N	/	Water quality monitoring
	2.3 Rules and norms of society	2.3.a	Existence of informal boards/groups resulting from cultural-historic development	Y/N	/	
		2.3.b	Solidarity in society: amount of donations given from the society/the local government to most climate impacted social groups	€		Floods, earthquakes…
		2.3.c	Availability of volunteer organizations/registers to activate in case of weather extremes and climate-related emergencies	Y/N	/	Civil protection; Army

Table 18: Test of the KPIs for the CLIMABOROUGH project impacts assessment. The Social capital.

CAPITALS	FACTORS	CODE	INDICATORS RELATED TO FACTORS	METRICS	THRESHOLDS	NOTES
3. INSTITUTIONAL CAPITAL	3.1 Organizational structure	3.1.a	Breakdown of responsabilities and tasks related to climate neutrality management into multiple departments/groups/divisions constitutes a primary barrier to climate objectives achievement	Y/N	/	Small cities don't have this problem
		3.1.b	Presence of a department/division/group 100% dedicated to climate management, with specific responsabilities and competences	Y/N	/	
		3.1.c	Presence of a department/division/group 100% dedicated to climate neutrality management, with specific responsabilities and competences	Y/N	/	outsourced to communal firm
		3.1.d	Inter-departmental coordination for multi-level governance: organization of regular alignment-meetings, presence of interdepartmental working groups	Y/N	/	
		3.1.e	Territorial coordination for multi-level governance: organization of regular alignment-meetings, presence of territorial working groups, networks at the territorial/regional level	Y/N	/	7 cities in Krk
	3.2 Skills and competences	3.2.a	Average level of education of local government's employees (or collaborators) responsible for climate-related issues	High school; university studies; more	/	
		3.2.b	Adequacy of the background studies of local government employees (or collaborators) to manage climate-related issues	High; Medium; low	/	
		3.2.c	Local government's employees have received training on climate-related issues	Y/N	/	
		3.2.d	Presence in most of the local government's departments of at least one nominated focal person for climate management	Y/N	/	
		3.2.e	Membership of local government's employees in non-governmental and governmental technical aid organisations (fire brigade, red cross, THW, etc)	%	% of the total number of employees +66%; +33%; -33%	Local civil protection group, local volunteer firebrigades group
		3.2.f	Presence of a figure (Resilience officier; Climate manager; etc.) with specific competences and skills for climate neutrality management in the local government	Y/N	/	
		3.2.g	Establishment of climate change research centres within universities or other institutions	Y/N	/	
		3.2.h	Establishment of external linkages/networks with research institutions (within country, within sub-regions, within Europe and/or globally)	Y/N	/	University of Rijeka; EU projects
	3.3 Transparency and trust in political actions	3.3.a	Level of (perceived) prioritization of climate action by local government	High; Medium; low	/	
		3.3.b	Percentage of population taking part in municipal elections on average (last 5 years)	n° of people	population 66% +33% -33%	65%
		3.3.c	Duration of the local government mandate	n° of years	4	
		3.3.d	Presence of climate-realted issues in the election programm of the last-elected political parties (local government)	Y/N	/	
		3.3.e	Periodic statistical surveys published reflecting the opinions of the population in regards to local government's performed work	Y/N	/	
		3.3.f	Organization of periodic formal meetings with stakeholders who are involved in continuous networking processes	n° of meetings/year	1-4 times/year; 5-9 times/year; +10 times/year	
		3.3.g	Presence of comprehensive anti-corruption policies	Y/N	/	
		3.3.h	Presence of laws/declarations, etc. in order to provide legal basis for the freedom of media	Y/N	/	national laws
		3.3.i	Periodic submission of new laws or decrees in a public document and/or publication on the institutional website	Y/N	/	

Table 19: Test of the KPIs for the CLIMABOROUGH project impacts assessment. The Institutional capital.

CAPITALS	FACTORS	CODE	INDICATORS RELATED TO FACTORS	METRICS	THRESHOLDS	NOTES
4. POLICY CAPITAL	4.1 Regulatory framework	4.1.a	Adoption of local mitigation plan and last update	Y/N	within the last 2 year; between 2-5 years ago; more than 5 years ago	https://www.grad-krk.hr/sites/default/files/files/02_zajednicki_akcijski_plan.pdf
		4.1.b	Adoption of local adaptation plan and last update	Y/N	within the last 2 year; between 2-5 years ago; more than 5 years ago	
		4.1.c	Adoption of local joint mitigation-adaptation plan (Climate neutrality plan) and last update	Y/N	within the last 2 year; between 2-5 years ago; more than 5 years ago	Zero Co2 strategy (2012-2020; 2020-2030); Secap 2020-2021
		4.1.d	Presence of cross-sectoral mitigation plans	Y/N	/	
		4.1.e	Presence of cross-sectoral adaptation plans	Y/N	/	
		4.1.f	Presence of sector-specific mitigation plans	Y/N	/	
		4.1.g	Presence of sector-specific adaptation plans	Y/N	/	
		4.1.h	Adoption of climate emergency plans and last update	Y/N	within the last 2 year; between 2-5 years ago; more than 5 years ago	https://www.grad-krk.hr/sites/default/files/files/02_zajednicki_akcijski_plan.pdf
		4.1.i	Permanency of climate related plans/laws/regulations (time period): update frequency	Frequency	1-2 years; 3-5 years; more than 5 years	
		4.1.l	Compulsory nature of the climate plans/law/regulations	Y/N	/	
		4.1.m	Compulsory nature of the climate adaptation plans/law/regulations	Y/N	/	
		4.1.n	Plans quality: integration of available climate services (climate projections/models, vulnerability assessment, risk assessments, cost-benefits analysis, etc.) into climate plans	Y/N	/	
		4.1.o	Plans quality: involvement of experts (external consultants/collaborators) for climate plans redaction	Y/N	/	
		4.1.p	Co-development of climate plans with stakeholders (citizens, private businesses, NGOs) trhough participatory processes	Y/N	/	https://www.grad-krk.hr/sites/default/files/files/02_zajednicki_akcijski_plan.pdf
		4.1.q	Inclusion of detailed stakeholders identification, budget, implementation and monitoring procedures, other details in the climate plans	Y/N	/	
		4.1.r	Implementation of monitoring procedures: regular monitoring and reporting on the application of the climate plans/laws/regulations	Y/N	/	

Table 20: Test of the KPIs for the CLIMABOROUGH project impacts assessment. The Policy capital.

CAPITALS	FACTORS	CODE	INDICATORS RELATED TO FACTORS	METRICS	THRESHOLDS	NOTES
5. FINANCIAL CAPITAL	5.1 Climate finance	5.1.a	Presence of a local investment strategy (budgeting) for the implementation of the current climate plans or climate actions	Y/N	/	Local municipality budget
		5.1.b	Main sources activated by the local government to obtain funds to tackle climate change	%	Public (regional): %40__ Public (national:% 60__ Public (international): %__ Private: %___	N.A.
		5.1.c	Presence of a specific person/group 100% dedicated to search and management of funds to tackle climate change within the local government	Y/N	/	
		5.1.d	Application to climate-realated European funding programmes within the last 5 years	Y/N	/	
		5.1.e	Application to non-European funding programmes relevant to climate change within the last 5 years	Y/N	/	
	5.2 Disaster funds/ Compensation of losses	5.2.a	Availability of governmental disaster compensation funds	Y/N	/	
		5.2.b	Ratio of public and private investments on disaster funding	%	Public: 50%__ Private: 50%___	N.A.
		5.2.c	Total yearly amount of expenses (percentage of the local GDP) on disaster funding	%	GDP +50%; -50%; +25%; -25%	
		5.2.d	Adquisition of an insurance coverage specific for climate-related losses by the local government and date of adquisition	Y/N Date:__/__/___ _	/	Our insurance policy (contract) covers all "higher force" damage on city properties such as floods, earthquakes, fires etc.
		5.2.e	Insurance ceiling of the local government's insurance coverage for climate-related losses	€	?	N.A.
		5.2.f	Presence of obligation for privates to adquire an insurance insurance coverage specific for climate-related losses	Y/N	/	
		5.2.g	Percentage of households having insurance related to specific climate-related issues	%	66%; +33% ; -33%	
		5.2.h	Percentage of enterprises having insurance related to specific climate-related issues	%	66%; +33% ; -33%	
		5.2.i	Percentage of damages that were covered by insurances during the last extreme events	%	66%; +33% ; -33%	

Table 21: Test of the KPIs for the CLIMABOROUGH project impacts assessment. The Financial capital.

CAPITALS	FACTORS	CODE	INDICATORS RELATED TO FACTORS	METRICS	THRESHOLDS	NOTES
6. INFORMATION CAPITAL	6.1 Information sources and quality	6.1.a	Local climate information sources: the local government acquires information from online portals only	Y/N	/	
		6.1.b	Local climate information sources: the local government contracted/established a partnership with specialized climate services* provider/s	Y/N	/	
		6.1.c	Local climate information sources: collaboration/ establishment of partnerships with other stakeholders to collect data on climate-related issues	Y/N	/	
		6.1.d	Local climate information sources: the local government contracted specialized consultants for climate information interpretation/elaboration	Y/N	/	
		6.1.e	Resolution of the available climate information at the local scale	cells dimension (mq)	?	N.A.
		6.1.f	Performance/acquisition of climate vulnerability assessments at the local scale	Y/N	/	
		6.1.g	Performance/acquisition of climate economic impacts assessments at the local scale	Y/N	/	
		6.1.h	Level of disaggregation of the available climate information at the local scale: acquisition of information on climate vulnerability and impacts on specific sectors/economic activities	Y/N	/	
		6.1.i	Level of disaggregation of the available climate information at the local scale: acquisition of information on climate impacts on specific target groups (women and/or socially excluded groups)	Y/N	/	
		6.1.l	Level of differentiation by user of the available climate services: user-driven climate services	Y/N	/	
		6.1.m	Acquisition of visulation tools: climate maps, infographic products, etc.	Y/N	/	Meteorological station (Krk municipality) https://www.grad-krk.hr/vrijeme
		6.1.n	Acquisition/translation of climate services products (informative material: factsheets, reports, etc.) into the local language	Y/N	/	
		6.1.o	Availability of urban sensors providing real-time climate monitoring data	Y/N	/	https://www.grad-krk.hr/vrijeme
	6.2 Information management practices & tools	6.2.a	Presence of local government's guidelines, policies, plans, obligations, standards for climate information management	Y/N	/	
		6.2.b	Presence of local government's specific guidelines for the interoperability between climate-related databases and information systems	Y/N	/	
		6.2.c	Accessibility of local climate information for citizens: availability of a dedicated section into local government's website	Y/N	/	
		6.2.d	Accessibility of local climate information for citizens: availability of a governmental Opensource central portal/platform housing all relevant local climate information	Y/N	/	https://meteo.hr/
		6.2.e	Availabilty of governmental dedicated apps for climate emergency management (alerts, early warnings, etc.)	Y/N	/	
		6.2.f	Availability of dedicated tools/apps for climate-related parameters monitoring by citizens (citizen science, participatory data collection)	Y/N	/	

Table 22: Test of the KPIs for the CLIMABOROUGH project impacts assessment. The Information capital.

The discussion of these results has been postponed in order to compare them, with the results of the same test in the 4 pilot cities (Torino, Cascais, Grenoble, Differdange). The KPIs will be adapted and refined in the light of the final and complete results.

3.2 The assessment of the Eco-system capacity KPIs - The city of Turin

3.2.1 The eco-system context of Turin

The city of Turin (Piedmont, Italy) extends for 130.2 km2, with 878,074 inhabitants. It is located in the Po Valley and extends over a flat urban area (239 m a.s.l.), and in a hilly area that reaches an altitude of 715 m. The city has high levels of air pollution, with an average PM10 of 2018 measured in the center of Turin of 33.0 μg m−3, and the maximum daily value, set at 50 μg m−3, exceeded 55 times. Urban planning faces the challenges of managing urban sprawl, addressing the urban heat island effect, and improving green infrastructure for biodiversity and ecosystem services.

Turin's historical and contemporary urban development presents an ideal context for applying and evaluating the developed methodology as the city is now in the process of developing the new land use plan (Piano Regolatore Generale). Furthermore, the city recently approved the Climate Resilience Plan (2020) and the strategic plan of Green Infrastructure (2021), proving a strong commitment to the integration of environmental subjects into urban planning.

Turin is a highly-sealed city, with certain urban districts that reaches the peak of 100% of sealed surfaces (e.g. the productive sites or the densely built-up residential areas) where each rainy phenomenon with a slightly higher intensity to normal conditions can provoke isolated flooding or other diseases.

It is well-known that imperviousness, among compactness, salinization, desertification, or the loss of organic matter, is the worst kind of degradation that the soil can receive from a land-use alteration. The so-called "land take" is defined as an unsustainable kind of land use alteration that compromise the possibility of the soil returning to its original natural properties. Therefore, urbanization and the related sealing process is considered an irreversible dynamic since it does not allow to return to natural conditions while maintaining the initial stock of the (limited) soil resource.

Turin is a deep "compact" urban catchment since the soil sealing rate for each land use demonstrates that the city has been subject to a concentrated anthropic transformation while creating a densely built-up core urban area with a low rate of permeability. Despite the eastern hilly area, the "Parco del Valentino," and the confluence between the Po and Stura Rivers, the remaining areas have fewer natural unsealed areas. This distinctive characteristic is confirmed by the Natural Difference Vegetation Index (NDVI), which assesses the "health" of the vegetation even inside the compact built-up area. Recent research based on this indicator demonstrates that a few urban districts are "porous" with healthy vegetation in the private space such as the Vanchiglia, the Vanchiglietta, Crocetta, and Borgo San Secondo.

Urban adaptation can be realistically pursued if the capacity to measure and evaluate the urban system is precise and reliable while reaching an accurate comprehension of the biophysical performance of the urban environment.

3.2.2 Assessing the Urban environment capital

The monitoring of the Urban environment capital for the city of Turin was developed through the assessment of the five Natural capital factors described above. The analysis was based on available data at city level by means of Integrated Evaluation of Ecosystem Services and Tradeoffs (InVEST) (Natural capital project, 2024) and ITree software (i-Tree Canopy, 2024).
InVEST models are spatially explicit, using maps as information sources and producing maps as outputs. InVEST returns results in either biophysical terms (e.g., tons of carbon sequestered) or economic terms (e.g., the net present value of that sequestered carbon). The spatial resolution of analyses is also flexible, allowing users to address questions at local, regional, or global scales.
InVEST models are based on production functions that define how changes in an ecosystem's structure and function are likely to affect the flows and values of ecosystem services across a land- or a seascape.
The Land Use/Land Cover (LULC) data were derived from the digital topographic dataset (BDTRE 2023) of the city freely available at Geoportale Piemonte. All the analyses were carried out using GIS software (ESRI ArchGIS Pro ver 3.2.2) and referred to the whole city level.
The results are described in the following sections.

EC1 Carbon Sequestration/Storage

The Carbon Sequestration model calculated an average pooling capacity of urban soils to store 47 tons per hectare (that includes soil + vegetation), which is a fairly good result. As for the maximum pooling capacity, as expected, is recorded in the hill with a maximum pooling capacity of 218 tons per hectare, which demonstrates how the city can benefit from a seminatural surrounding that can play a vital role in regulating the quantity of air pollutants and generate oxygen.

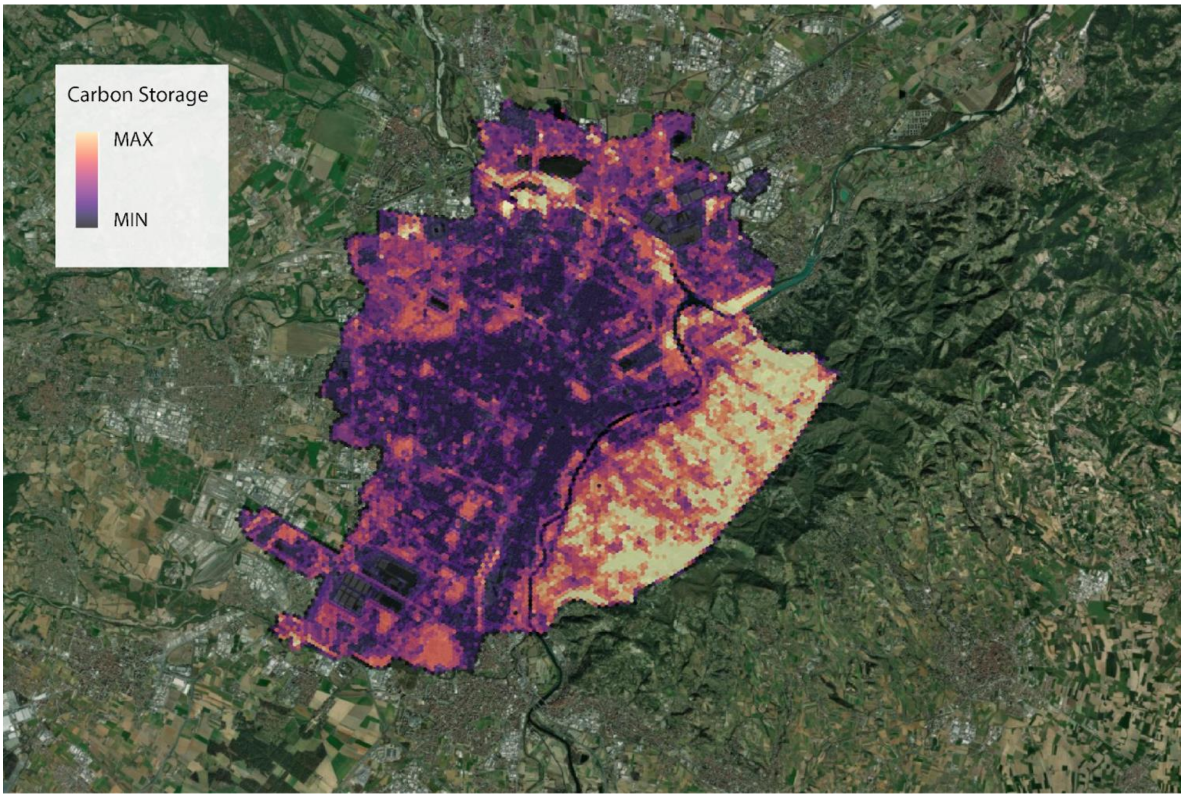

Figure 7: Carbon Storage for the city of Turin. LabPPTE-DAStU elaboration.

EC2 Air Purification

The input required by the models includes tree structure data, meteorological and pollution data, and location characteristics. For tree structure, information such as tree species, diameter at breast height (DBH), and tree height were used. Meteorological data were collected from the weather station "Cric della Croce," while pollution data was obtained from four different stations across Turin: Rebaudengo, Quadrilatero, Mirafiori nord, and Lingotto. These stations monitor various pollutants such as CO, NO2, SO2, O3, PM2.5, and PM10 (Figure 8).

For running the model, the Turin tree register has been collected and codified according to the I-tree model. The GPS coordinates of the individual trees were also entered in order to subsequently spatialize the outcome. Furthermore, some limited simplifications and adjustments were done for records with the lack of some land registry data.

The reference year for the data is 2015, with data up to 2021 used for the models, excluding the years impacted by the COVID-19 pandemic (2020, 2021) due to significant reductions in pollutants. Additionally, preceding the pandemic, only data from meteorological stations in the city of Alessandria, located approximately 90 km away, are available. Location characteristics such as climate region, population, and density are also considered in the models.

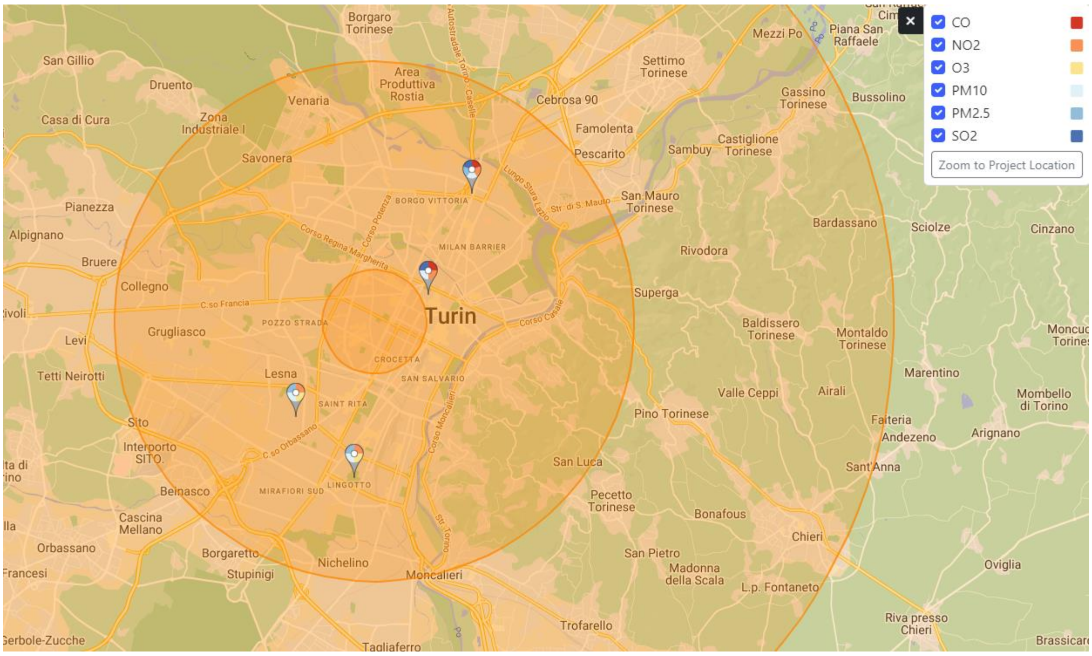

Figure 8: I-Tree ECO interface for selecting weather stations

The Air Purification Model estimated the pollution removal by trees in the city of Turin, the urban forest of Turin has 116.300 with a tree cover of 594.48 ha. The most common species of Trees are Oriental planetree, Basswood, European hackberry. The estimation of pollution removal is 55 tons/year (Ozone (O3), Carbon monoxide (CO), Nitrogen dioxide (NO2), Particulate matter less than 2.5 microns (PM2.5), Particulate matter less than 10 microns and greater than 2.5 microns (PM10), and sulfur dioxide (SO2)).

More specifically, trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year so the amount increases with the size and health of the trees. In Turin, the *carbon storage* (i.e. the amount of carbon bound up in woody material above and below ground) is 40.59 thousand tons, the trees are estimated to store 40,600 tons of carbon. Oriental planetree stores and sequesters the most carbon (approximately 16.1% of the total carbon stored and 20.5% of all
sequestered carbon.). While the *carbon sequestration* (i.e. refers in UFORE to the removal of carbon (in the form of carbon dioxide) from the atmosphere through the process of photosynthesis) is 1.566 thousand tons of carbon per year.

EC3 Habitat Quality

The Habitat Quality Model in Torino presents a minimum value of 24.29 and a maximum value of 92.17. Well-maintained habitats are mainly distributed in Turin hill and along the main tributaries of the Po Rives that create an ecological connection between the western and eastern borders of the city (Dora and Stura). Although the hill displays higher values, it is noticeable how they are clusterized and not diffused, meaning that the hill is a highly anthropized system that threatens the environment. The Dora Stream displays good values of Habitat Quality around the Pellerina Park and in the Parco Dora parks, but from there on, there is no trace of higher values, meaning that the Riverbed has been highly channelized and heavily anthropized, leaving no space for nature. Differently, the Stura stream is more natural, and along its course, it can be well-recognized as a higher Habitat Quality.

Figure 9: Habitat Quality for the city of Turin. LabPPTE-DAStU elaboration.

EC4 Cooling Capacity

As for heat mitigation, Torino presents a minimum value of 27.92 and a maximum value of 92.87. Four main core mitigation areas can be detected as hotspots to cool down temperatures during hot days. The hill, including the northeastern part where the Stura tributary reaches the Po River. Here the Parco della Colletta plays a vital role in connecting the natural areas of the hill with the peri-urban agricultural system. The Basse di Stura cluster is a strong mitigation point, as is the Parco della Colletta. In the south, Sangone Park seems to have a dimension that provides enough cooling capacity, thus representing the fourth hotspot of the city. It should be mentioned that, for this specific Ecosystem Service, the Po River excavates a channel that crosses the city from south to north and provides air circulation with a gentle freeze even during hot, stagnant days. Unfortunately, here the model does not account for wind interaction because it has been designed only to assess the capacity of natural soil features (such as vegetation) to provide cooling capacity.

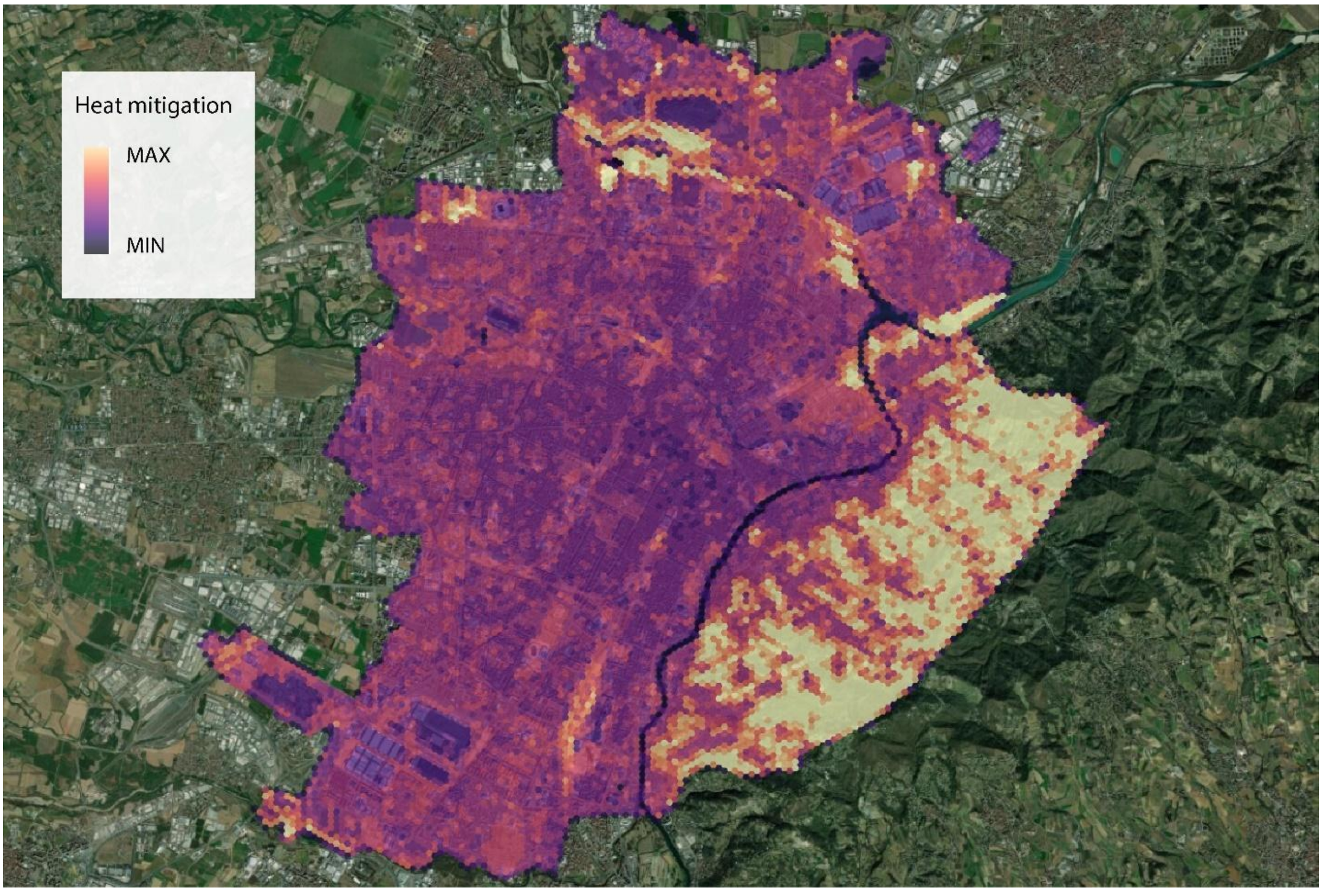

Figure 10: Heat mitigation for the city of Turin. LabPPTE-DAStU elaboration.

EC5 Water regulation (Urban Flood Risk Mitigation)

As for heat mitigation, the Urban Flood Risk Mitigation integrates the information on land uses with soil hydraulic conductivity. The retention index indicates, for each pixel, the amount of total yearly water volume that can be retained by soil. Of this amount a small fraction goes to recharge the aquifer (percolation) while the remaining part evapotranspirates through roots absorption.

In Turin, the model indicates that the 54% of the annual rain volume infiltrates on soil, while the 46% goes on runoff. Only a fraction of 1,34% of the infiltrated soil percolates and recharge the deep acquifer of the city (this amount correspond to 1.636.020 cube meters which is a valuable measure that can be used to see if the water demand is satisfied by the infiltration).

However, the average infiltration capacity only in the dense urban areas is much lover of the average, often falling below the 10% which means that the large majority of the rainwater goes on runoff in the urban catchment. As expected, the hill has in general a good retention capacity, even though the soils are not performing well in terms of water conductivity.

Figure 11: Water retention for the city of Turin. LabPPTE-DAStU elaboration

3.3 Co-designing the tool: the "cities speed-dating" and KPIs participatory design workshop

Much effort has been put in designing the CLIMABOROUGH impacts assessment and monitoring tool in such a way that it can be easily applied and re-applied by local administrations independently. The aim is actually to expand its function: it is intended to not only be used by the WP1 research teams as a control-tool to monitor the advancements of CLIMABOROUGH project, but rather all the 12 CLIMABOROUGH partner cities will be provided with a tool for the self- assessment and monitoring of their progress towards achieving climate neutrality.
With this in mind, the construction of the tool includes testing the prototypes developed step-by-step throughout the whole development process and in various cities, organizing different KPIs co-design workshops with the 12 CLIMABOROUGH partner cities' representatives and testing the final version in 4 pilot cities (Torino, Cascais, Grenoble and Differdange) to achieve the final validation of the KPIs.
The ultimate goal goes far beyond the CLIMABOROUGH's project objectives and its time horizon: our ambition is to design an innovative climate neutrality self-assessment and monitoring tool which can be employed by cities all around the world to identify their weaknesses and accordingly select *ad-hoc* actions and measures to advance towards the achievement of climate neutrality.
With this in mind, we carried out a KPIs participatory design workshop with the 12 CLIMABOROUGH partner cities' representatives. This was conducted in an in-presence modality at the CLIMABOROUGH General Assembly held in the city of Maribor (SL), on the 12th of March 2024.

The main scopes of the workshop were:
- explaining the structure of the tool (the differentiation of the proposed KPIs into six sets corresponding to six capitals);
- verifying the comprehensibility and ease of use of the proposed KPIs;
- collecting the cities' feedbacks on their usefulness and soliciting suggestions for alternative/additional indicators to be integrated in the sets of KPIs.

The KPIs will be adjusted and refined based on the results of the workshop.

The workshop was structured in two sessions:
1. The "cities speed-dating" session (1.5 hours);
2. The post-its & stickers session (30 minutes).

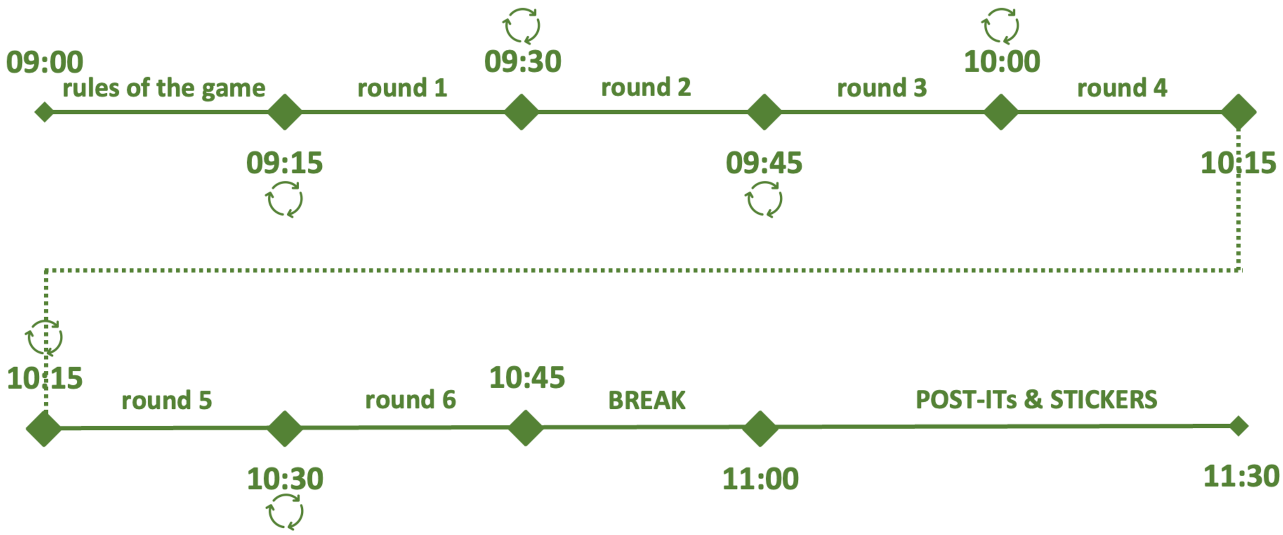

Figure 12: timeline of the CLIMABOROUGH workshop held in Maribor (SL), March 2024.

The "cities speed-dating" session consisted in an interactive moment between the CLIMABOROUGH research teams from WP1and WP3 and the representatives of the 14 partner cities which attended the General Assembly.
Six members of the research teams sat at the six tables, each of which was dedicated to one capital. The 14 cities were divided into couples according to their characteristics (same Climhub; similar city challenge; similar adaptation and mitigation solutions acquired through public procurements). Each couple sat at one capital table.
The research teams members submitted one fillable table reporting the KPIs related to the specific capital to the representatives of the partner cities, in paper form. Each indicator was presented individually to the representatives of the cities.
The following questions were posed to the cities' representatives:
1. Is this indicator comprehensible for you?
2. Could you already provide the requested information or do you know who within your city's departments could provide it?
3. Is this indicator useful to assess the related factor in your opinion?
4. Could you suggest an alternative/additional indicator to assess this factor?
Each member of the research teams took note of the answers of the two cities sat at his/her table.
The consultation rounds lasted 15 minutes; every 15 minutes, a timer ringed and the research teams members changed table to meet the next two couples of cities' representatives.

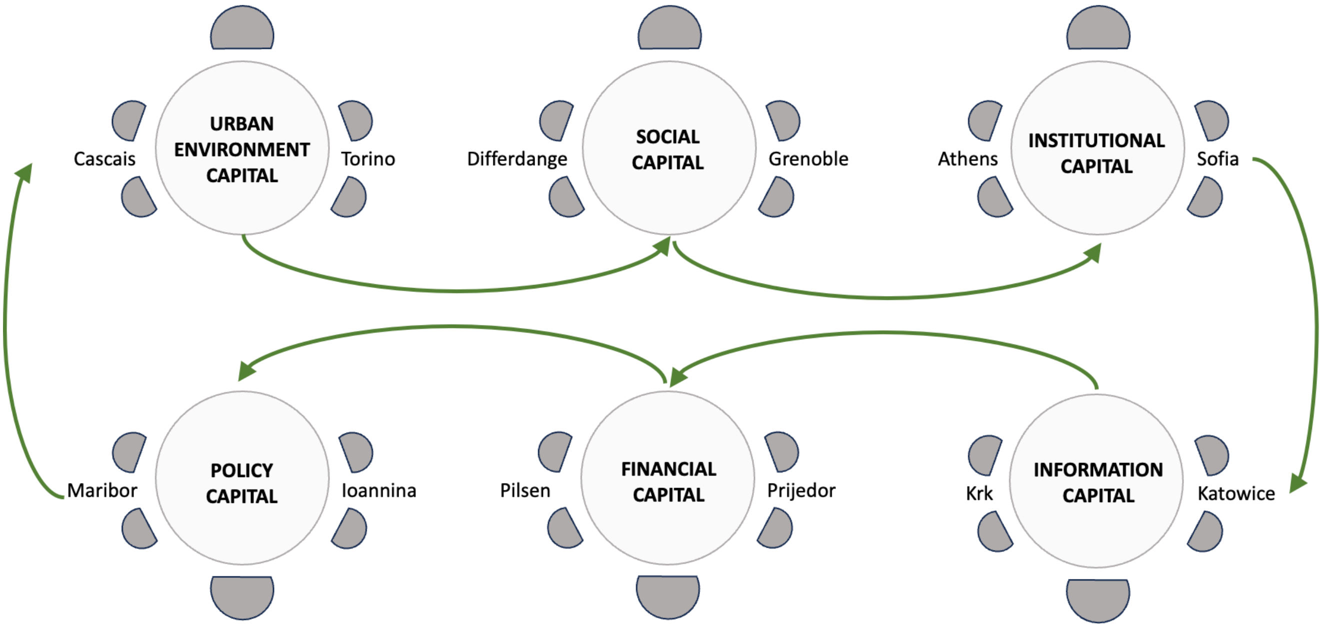

Figure 13: The setting of the “cities speed-dating” session: the “cabaret setting” and the capitals tables.

After a break of 15 minutes, the representatives of the 14 partner cities were invited to attend the second session of the workshop: the post-its & stickers session.
The same fillable tables presented in paper form (A3 format) to the cities’ representative during the “cities speed-dating” session were printed out in A0 format, one for each capital. The six posters were attached to the wall, one beside the other. Some post-its and stickers were distributed among the workshop participants.
The representatives could chat at some standing tables and exchange ideas on the KPIs emerged during the first session (“city speed-dating”). After 30 mins, they were called to stick on the posters, in correspondence of each indicator, the post-its and the stickers reporting their observations and suggestions.

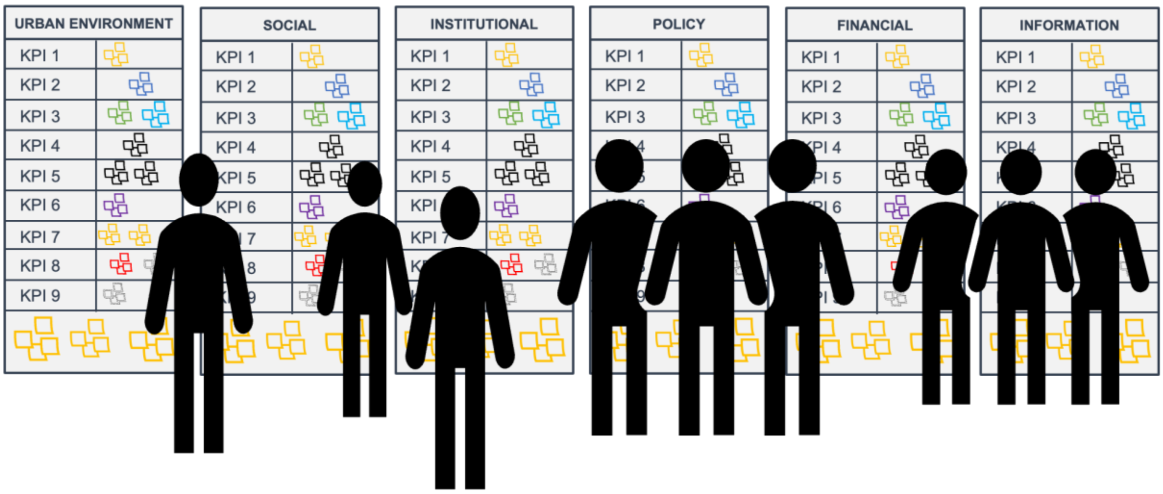

Figure 14: The setting of the "post-its & stickers" session: discussing capitals' indicators and suggesting changes and integrations.

The final results of the workshop described in this section will be further deepened through a continuous and close cooperation with the partner cities. The cities' feedback, once refined, will serve as a basis for integrating and tailoring the sets of KPIs.

4. Conclusions

The periodical assessment of cities' progress in the journey towards climate neutrality is a fundamental activity in the perspective of raising risks due to anthropogenic climate change. It allows to keep track of the impacts of mitigation and adaption measures and actions on urban systems and to monitor their medium- and long-term benefits.

Achieving ambitious climate goals and managing the transition towards climate neutrality requires adequate organizational structures of the involved subjects, multi-disciplinary knowledge and competences, ad-hoc support tools and optimized information management processes. Local governments often lack the resources and the capacities to fulfill all these requirements. Identifying gaps and criticalities in urban institutions and processes is the first step in the design of possible solutions.

The scope of the CLIMABOROUGH assessment and monitoring tool is not ranking cities by their advancement status but rather detecting weak points in their governance models and processes and gaps in their tangible and intangible resources (capitals) in order to identify rooms for improvements and implementing effective climate measures to support cities' in their transition towards climate neutrality.

Attention has been paid to designing this instrument in such a way that it can be easily applied and re-applied by local administrations independently. The aim is actually to expand the function of the CLIMABOROUGH impacts assessment and monitoring tool: it will not only be used by the WP1 research teams as a control-tool to monitor the advancements of CLIMABOROUGH project, but rather all the 12 CLIMABOROUGH partner cities will be provided with a tool for the self- assessment and monitoring of their progress towards achieving climate neutrality.

Furthermore, the assessment of cities' gaps and criticalities across six capitals is a possible approach to support cities and provide them with the knowledge to intervene on the most urgent aspects of governance or urban environment, and thus to prioritize most impactful actions.

The next step in the research will be the application of the tool in 4 pilot cities chosen among the project partner cities: Torino, Cascais, Grenoble and Differdange.

The KPIs and the tool's structure will be adjusted on the basis of the results of these first experiences.

The observation of real cases through the close collaboration with CLIMABOROUGH partner cities will contribute to verify our preliminary hypothesis that the gaps and criticalities affecting urban environment factors and climate neutrality governance processes lie not much in the single performed actions or cities' capitals as, instead, in the complex relationships involving multiple stakeholders and in the systems of formal and informal norms and regulations regulating these relationships.

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