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Integration of multiple methodologies to evaluate effects of Nature Based Solutions on urban climate mitigation and adaptation

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Abstract. Nature Based Solutions contribute both to mitigate and to adapt the cities to the impacts caused by climate change at urban level. Several methods and tools exist for assessing each strategy. However, none of them allow to cover the whole steps included from analyzing climate trends that could affect the cities, to NBS effectiveness. This paper reviews and classifies existing methods according to the relevant steps of climate resilience and NBS effectiveness, and a combination of various of those methods is presented in a practical case study. Bottom-up city energy, economic and environmental modelling have been performed to understand mitigation effects of NBS implementation at building and neighborhood level. Urban hydrodynamics and fluid dynamics have been modelled too, allowing the estimation of the adaptation effectiveness of the NBS scenarios in flooding and temperatures reduction respectively. Moreover, city vulnerability and urban risks, considering IPCC scenarios regarding climate trends, have been assessed to understand the areas of the city more vulnerable to the impact of climate change. Results show that strategies and climate hazards has been worked in a split way and there is a need to connect better mitigation and adaptation information to facilitate the municipalities taking robust decisions regarding the NBS implementation.

1. Introduction

Urbanization is widely acknowledged to be on an upward trend with 66% of the global population expected to be living in cities by 2050 [1]. Projections of climate change show increasing frequency and severity of extreme weather events, such as heatwaves. Such events, coupled with the UHI are likely to amplify the challenges facing this urban growth [2].

In this context, the European Union considers between their four main goals in this topic, the need of developing climate change adaptation and mitigation strategies. In order to promote this goal, for the current budget period 2014-2020, the European Commission has proposed that at least 20% of the budget (Multiannual Financial Framework) should contribute to climate change objectives, helping to ensure substantial support for adaptation and mitigation action in the Member States [3].

Following this, in March 2014, the European Commission launched the Mayors Adapt initiative on urban adaptation. It merged in 2015 with the Covenant of Mayors, combining urban adaptation and mitigation into an integrated approach. Today, the EU Covenant of Mayors for Climate & Energy brings together thousands of local governments voluntarily committed to implementing EU climate and energy objectives [3]. The trend driven by the Covenant of Mayors for Climate and Energy (CoM) is to include



both climate and mitigation aspects [4]. This is also aligned with IPCC approach which considers that Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change [2].

In this global context of mounting challenges (e.g., climate change) and human activities (e.g., rapid urbanization), this Special Issue of Environmental Research attempts to lay the theoretical and applicative foundations of the Nature based solutions (NBS) concept by focusing on the most recent innovative strategies and scientific advances for building resilient landscapes and cities [5]. NBS are living solutions inspired, continuously supported by and using nature, designed to address various societal challenges in a resource-efficient and adaptable manner and to provide simultaneously economic, social and environmental benefits [6]. Having recognized NBS as one of the most comprehensive approaches for developing resilient landscapes and cities, governments and scientific communities are currently faced with the challenge of moving from general pronouncements to practical applications [5].

This paper presents the analysis of the existing methods and tools for assessing NBS effectiveness to mitigate and/or adapt the urban environments to climate change. Considering the trends driven by the most relevant entities about considering both mitigation and adaptation contributions, special focus has been put to identify methods that allow considering both strategies with the idea of providing an integrated approach.

2. Procedure followed

The procedure followed to understand the potentialities of the methods and tools to provide robust information regarding NBS effectiveness to climate change mitigation and adaptation has been done in 4 main steps:

- Step 1: Climate resilience methodology. Definition of all the features that a climate resilient methodology must cover.
- Step 2: Methods selection and characterization. Identification of all the methods and tools that can cover at least one part of the previously defined features.
- Step 3: Methods classification. Classification of the methods according to the relevant steps of climate resilience and NBS effectiveness that they cover.
- Step 4: Case study. Analyze in a practical case study a combination of various of those methods

2.1. Step 1: Climate resilience methodology.

The ambition of the climate resilience methodology as is understand in this paper, was the identification and organization of all the potential issues of interest in the context of climate change and NBS fields. Following objectives were defined for the methodology:

- It must allow understanding how the climate trends can affect the cities.
- It must consider how to assess the climate hazards that could affect the cities.
- It must allow assessing mitigation and/or adaptation strategies.
- It must include how to assess the effectiveness of the NBS to improve city resilience.

These objectives guided a completed state of the art revision which was supported in the identification and analysis of more than 80 references [7]. These references include more than 60 scientific articles identified thanks to key words such as climate resilience, mitigation, adaptation, Nature based solutions, urban climate trends, urban heat island effect, etc. Related projects and networks were identified and analyzed too, providing a detailed view of the of the state of the art.

From the literature review, information was extracted in order to establish the basis of the methodology development. This information attends to the climate issues, scale (region, city, district, object), target of the measures (adaptation, mitigation, resilience), type of NBS considered, indicators used, actuation areas, etc.

The literature review had as a result the collection of all the features of interest that a methodology that allows assessing from climate trends to NBS effectiveness must cover:

- 1) Climate trends: air temperature, Rainfall/precipitation, air quality
- 2) Climate threats/impacts/hazards: Colder winters and warmer summers, Urban heat Island effect (UHI), runoff, air pollution, water quality, wind field.
- 3) Strategies: Mitigation and adaptation
- 4) Indicators to assess urban vulnerability and risks: Building cooling and/or heating energy demand reduction, global warming potential reduction, primary energy demand reduction, runoff reduction, carbon sequestration, external air temperature reduction.
- 5) Nature based solutions: parks and gardens, structures associated to urban networks, structures characterized by food and resources production, natural and semi-natural water bodies and hydrographic networks, constructed wetlands and built structures for water management, green roofs, urban planning strategies, works on soil, vertical structures (green walls and façades), direct human interventions.

2.2. Step 2: Methods selection and characterization.

This step consisted on the identification of all the methods and tools that can cover at least one part of the previously defined features of the methodology. After the identification, the methods have been characterized according to the mentioned features.

2.3. Step 3: Methods classification.

The classification of identified methods and tools according to their suitability for the urban climate resilience and NBS methodology application has been done by using the RACER method. RACER is an evaluation framework designed by the European Commission to assess the value of scientific tools for use in policy making [8, 9, 10]. RACER stands for Relevant, Accepted, Credible, Easy and Robust:

- Relevant – e.g. closely linked to the objectives to be reached.
- Accepted – e.g. by staff and stakeholders.
- Credible for non-experts, unambiguous and easy to interpret.
- Easy to monitor – e.g. data collection should be possible at low cost.
- Robust – e.g. against manipulation.

This generic approach has been adapted to the objectives of the method classification:

- **Assessing urban climate issues:** methods that take into account issues related to climate, (such as temperatures, rainfall, air quality) are considered relevant for the purpose of the methodology.
- **Consideration of different scales:** methods that cover object, neighbourhood and city scales

are needed in order to fully characterize the NBS effectiveness over the climate resilience of the city.

- **Analysing all the stages:** from identification of threats to the analysis of NBS effectiveness. Methods that allow assessing the whole process are presented as suitable for the purpose of the methodology. However, according to the specific characteristics that this methodology wants to fulfil, it was considered challenging finding a method that could assess the whole process.
- **Assessing NBS:** as Nature Based Solutions are the focus of the project, methods that consider several NBS are included as relevant.
- **Feasibility to apply the method:** data, tools and information availability for the application of the methods by the municipalities, it was considered interesting too.

These dimensions have been considered as the main criteria to appraise the climate resilience of the cities and NBS.

2.4. Step 4: Case study. Donosti/San Sebastian city (north of Spain)

A real case study has been defined and the most promising methods according to the RACER, to the classification and to the issues of interest for the municipality, have been selected to understand the integration options of them.

It is important to note that after identifying all the potential interesting methods regarding the climate change and NBS fields, several expectations have been defined to be answered by the method (or methods in plural):

- understanding current situation (climate threats currently affecting the municipality),
- identifying potential future impacts due to the climate change if there is no intervention (BAU),
- building NBS scenarios to try to minimize the potential impacts,
- assessing the scenarios and
- selecting the most suitable NBS solutions according to their effectiveness

Following this approach, the case study of has been defined and performed and integration options have been studied:

- Envi-met has been used to understand the effectiveness of the NBS to adapt the neighbourhood to the expected temperatures increase.
- CityCAT, on the other hand, has been used to understand the NBS effectiveness to run-off reduction.
- ENERKAD has been used to understand the mitigation effects of the NBS in the energy demand of the buildings.
- NEST has been used to understand the NBS effectiveness to reduce the climate impacts at the neighbourhood scale.

3. Results

3.1. Methods characterization: Climate resilient features covered by analysed methods.

Full list of considered methods is given in chapter 3.2. In total, 21 methods have been studied and characterized. Results from the methods characterization is given in table 1.

Table 1. Climate resilient features covered by analyzed methods

Climate resilient feature	Climate resilient (sub)feature	Number of methods
Strategy	Mitigation	8
	Adaptation	14
	Mitigation & Adaptation	5
Climate trends	Air temperature	11
	Rainfall / precipitation	11
	Air quality	9
Climate threats/impacts	Colder winters, warmer summers	12
	Urban Heat Island	12
	Runoff	12
	Air pollution	13
	Water quality	8
Indicators	Wind field	10
	Building cooling and heating energy demand reduction	9
	Global warming potential reduction	6
	Primary energy demand reduction	7
	Runoff reduction	11
	Carbon sequestration	5
Scale	External air temperature reduction	10
	Object	15
	District	17
	City	17
	Up to the city	15
Nature Based Solutions	Parks and gardens	15
	Structures associated to urban networks	15
	Structures characterized by food and resources production	13
	Natural and semi-natural water bodies and hydrographic networks	13
	Constructed wetlands and built structures for water management	14
	Green roofs	17
	Urban planning strategies	12
Works on soil	13	
Nature Based Solutions	Vertical structures (Green walls and facades)	15
	Direct human interventions	12

3.2. Methods classification according to their suitability to assess from climate trends to NBS effectiveness.

Table 2 summarizes the results obtained from the RACER assessment applied to selected methods together with the number of features of the methodology that they consider.

Table 2. Methods classification according to their suitability to assess from climate trends to NBS effectiveness

Method	RACER position	Methodology features covered (tot 32)
Envi-MET	1	21
Library of Adaptation Option	2	25
Design Builder	3	9
EPA Storm Water Management Model (SWMM)	4	18
Enerkad	5	13
Green Pass	6	23
HAVURI	7	26
NEST	8	14
CITY-CAT	9	18
Soil and Water Assessment Tool (SWAT)	10	19
Climate-ADAPT web platform	11	7
Rayman	12	8
Fault tree analysis (FTA)	13	21
SIRVA	14	26
Simile	15	22
URB-CLIM	16	19
EPESUS	17	22
Enviro-HIRLAM	18	9
PLINIVS models	19	6
IVAVIA	20	27
IPCC projections	#NA	7

TEB, i-tree eko and Solweig methods have been identified as potential methods of interest and will be included in next steps of the work done in this field.

3.3. CityCAT, ENVI-met, ENERKAD and NEST methods applied to a real case study.

CityCAT method allows to calculate quantitatively the effectiveness of any type of Nature Based Solution regarding runoff reduction, at any scale. CityCAT allows the visualization of the results given as a reduction of a high of the sheet of water and as runoff reduction in centimetres. Although, the model requires a very time consuming cartography pre-processing, once this work is done, the simulation of different scenarios with different NBS configurations or different meteorological conditions, is very easy to perform. Moreover, ENVI-met model, needs very similar inputs to the ones required for CityCAT. Therefore, the information can be shared for both models.

ENVI-met method allows to calculate quantitatively the effectiveness of any type of Nature Based Solution regarding temperature reduction, at neighbourhood scale. Meteorological information representative of the study site matches with the information demanded by CityCAT. According to ENVI-met results, the effectiveness of NBS temperature reduction varies depending on the selected

moment of the day and according to the solar radiation. Unfortunately, there is a lack of consensus on how is the better way of measuring the thermal effectiveness of adaptation measures. The scientific community is working on standardising thermal effectiveness related process that is, the way of measure the thermal variable and the metrics to express the effectiveness.

Enerkad allows studying the NBS effectiveness to reduce the energy demand of the buildings. In this sense, the implementation of NBS it is considered a mitigation strategy. This is because the aim is to reduce the consumption of energy and, as a consequence, to minimize the environmental impacts due to energy consumption. Enerkad can be also linked with ENVI-met, but strong efforts are needed to obtain the whole hourly temperatures of a year with this approach, other urban climate tools like UWG would be more adapted¹ as it directly provides local climate temperature in a district in function of a temperature from close rural meteo station, depending on the district land use. It also can be use with weather projection to add the local NBS effect. Regarding the NBS, it must be note that Enerkad is focused on buildings and, as a consequence, only NBS that can be implemented in buildings, such as green roofs and green façades, are going to have remarkable effects on the results.

NEST tool has been selected for the case study in order to understand the NBS effectiveness to reduce the climate impacts at the neighbourhood scale. In this sense, the implementation of NBS it is considered a mitigation and adaptation strategies because it allows the assessment of the impacts of:

- (1) Vegetation on GWP and runoff reduction
- (2) Permeable pavements and green roofs on runoff reduction

Runoff reduction is given in NEST in terms of absorbed water (green spaces and mineralised areas with low permeability) and unabsorbed water in m³/year. This kind of results differs from the ones provided by CityCAT (runoff reduction in cm). Therefore, depending on the objective of the study, one or the other could be more suitable.

Enerkad results can also be translated to GWP reduction due to NBS implementation. Nevertheless, the scale at which Enerkad and NEST work is different. A bottom up approach can be applied to compare the results of both methods but and, again, depending on the aim of the study could be more suitable selecting one of them.

4. Conclusions

Nature Based Solutions contribute both to mitigate and to adapt the cities to the impacts caused by climate change at urban level. Several methods and tools exist for assessing each strategy. However, none of them allow to cover the whole steps included from analysing climate trends that could affect the cities, to understand the NBS effectiveness to mitigate and/or to adapt the cities.

Results show that strategies and climate hazards has been worked in a split way. Some methods are focused in a specific climate feature, and do not provide information about other potential benefits of implementing NBS. Analysing the same NBS scenarios with different methodologies, reflects other advantages associated to NBS implementation. Data needed for the methods and the treatment of it was similar in some cases. Nevertheless, is not possible to put together the results obtained with each method and the different approaches do not allow the comparison between results. Therefore, there is a need to connect better mitigation and adaptation information to facilitate the municipalities taking robust decisions regarding the NBS implementation. This conclusion can be also transfer to the specific field of adaptation.

¹ <http://urbanmicroclimate.scripts.mit.edu/uwg.php>

This paper presents just the starting point of the work to be done in this field. Conducting a full study, from understanding climate trends, to identify urban vulnerabilities and risks, to analyse nature based solutions effectiveness to minimize the effects of climate, is something that the municipalities are already demanding. Scientific community must answer to this demand in a robust way and must help the municipalities in the decision making processes regarding the most suitable NBS to be implemented. As a result, the introduction of NBS in the cities will be supported too and the climate change effects will be minimized.

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