



**Grant Agreement No.:** 730468

**Project acronym:** Nature4Cities

**Project title:** Nature Based Solutions for re-naturing cities: knowledge diffusion and decision support platform through new collaborative models

**Research and Innovation Action**

**Topic:** SCC-03-2016: New governance, business, financing models and economic impact assessment tools for sustainable cities with nature-based solutions (urban re-naturing)

**Starting date of project:** 1<sup>st</sup> of November 2016

**Duration:** 48 months

## D4.1 – Development of a multi-scale system dynamics assessment framework for nature-based solutions in cities

Organisation name of lead contractor for this deliverable: LIST		
Version 4 – Rev.2	Due Date	04/30/2018
	Submission Date	04/30/2018
	Authors	Babí Almenar, J., Petucco, C., Rugani, B.; ( <b>LIST</b> ) Egusquiza, A., Arana Bollar, M.; ( <b>TEC</b> ) Larrey-Lassalle, P., Pousse, M.; ( <b>NBK</b> ) Musseti, A.; ( <b>RINA</b> ) Yilmaz, Ö., Basoglu, D.; ( <b>EKO</b> ) Szkordilis, F., Körmöndi, B.; ( <b>MUTK</b> ) Kraus, F.; ( <b>G4C</b> ) Laïlle, P.; ( <b>P&amp;C</b> ) Serna, V., Martín, S.; ( <b>CAR</b> ) Köroglu, T.; ( <b>CAN</b> ) Hevizi, B.; ( <b>SZEG</b> ) Breton Ramos, E. M.; ( <b>AH</b> ) Donati, R., Colombo, S.; ( <b>CMM</b> ) –
Dissemination Level		
<b>PU</b>	Public	
<b>CO</b>	Confidential, only for members of the consortium (including the Commission Services)	X

Nature4Cities – D 4.1 – Development of a multi-scale system dynamics assessment framework for nature-based solutions in cities

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730468

**Recommended citation:**

Babí Almenar, J., Petucco, C., Rugani, B., Egusquiza, A., Arana Bollar, M., Larrey-Lassalle, P., Pousse, M., Musseti, A., Yilmaz, Ö., Basoglu, D., Szkordilisz, F., Körmöndi, B., Kraus, F., Laille, P., Serna, V., Martín, S., Köroglu, T., Hevizi, B., Breton Ramos, E. M., Donati, R., Colombo, S., 2018. Development of a multi-scale system dynamics assessment framework for nature-based solutions in cities – Deliverable 4.1 of Nature4Cities (“Nature Based Solutions for re-naturing cities: knowledge diffusion and decision support platform through new collaborative models”). European Commission Grant Agreement No. 730468. Released on April 2018 by the Luxembourg Institute of Science and Technology (LIST).

**Disclaimer**

This project has received funding from the European Union’s Horizon 2020 Research and Innovation Programme under grant agreement No. 730468. The information and views set out in this report are those of the authors and do not necessarily reflect the official opinion of the European Union. Neither the European Union institutions and bodies nor any person acting on their behalf may be held responsible for the use which may be made of the information contained therein.

# Table of Contents

<b>Table of Contents</b> .....	<b>2</b>
<b>List of Figures</b> .....	<b>5</b>
<b>List of Tables</b> .....	<b>6</b>
<b>Glossary</b> .....	<b>7</b>
<b>Executive Summary</b> .....	<b>9</b>
<b>1. Introduction</b> .....	<b>13</b>
1.1. Background and Purpose.....	13
1.2. Contribution of partners .....	14
1.3. Target audience.....	14
1.4. Relation to other tasks of Nature4Cities .....	15
1.5. Report structure .....	17
<b>2. Methodological approach</b> .....	<b>15</b>
2.1. Identification of UC-ES-NBS relations .....	16
2.2. Identification of ES, structures & processes .....	17
2.3. Characterization of urban systems.....	18
2.4. Representation of NBS & urban systems .....	19
2.5. Collection of data and revision of previous works.....	20
<b>3. Relation among Urban Challenges, Ecosystem Services, and Nature-based solutions</b> .....	<b>21</b>
3.1. Urban challenges and sub challenges selected .....	21
3.2. Ecosystems services .....	23
3.2.1. Classification framework .....	23
3.2.2. Selection of ecosystem services .....	24
3.3. Nature-based solutions .....	27
3.3.1. Conceptualization .....	27
3.3.2. An urban NBS typology for modelling purposes .....	28
3.3.3. Selection of Urban NBS .....	34
3.3.3.1. Initial-selection of Urban NBS Type 3 based on the literature review .....	34
3.3.3.2. Potential NBS type 2 and 1, based on pre-selected NBS type 3. ....	37
3.3.3.3. Short comparison with the case studies at WP7. ....	39
<b>4. Biophysical structures, socio-ecological processes, and the selection of ES Indicators</b> .....	<b>41</b>
4.1. Relation between biophysical structures, ecological processes, and social and ecological factors .....	41

4.1.1.	Regulation of chemical composition of atmosphere .....	42
4.1.2.	Regulation of temperature and humidity.....	44
4.1.3.	Hydrological factor and water flow regulation .....	45
4.1.4.	Regulation of the chemical condition of freshwaters by living processes.....	45
4.1.5.	Filtration, sequestration, storage and accumulation by plants .....	47
4.1.6.	Bio-remediation by plants .....	47
4.1.7.	Characteristic of living systems enabling activities promoting health or enjoyment .....	49
4.1.8.	Characteristics of living systems enabling aesthetic experiences.....	49
4.1.9.	Noise attenuation.....	50
4.1.10.	Maintaining nursery populations and habitats.....	51
4.1.11.	Cultivated plants grown for nutrition, material, and energy purposes .....	51
4.2.	Selection of ecosystem services indicators .....	52
4.2.1.	Regulation of chemical composition of atmosphere .....	52
4.2.2.	Regulation of temperature and humidity.....	52
4.2.3.	Regulation of hydrological cycle and water flow .....	53
4.2.4.	Filtration, sequestration, storage and accumulation by plants .....	53
4.2.5.	Regulation of chemical conditions of freshwater by living processes.....	53
4.2.6.	Bio-remediation by plants .....	54
4.2.7.	Characteristics of living systems enabling activities promoting health or enjoyment .....	54
4.2.8.	Characteristics of living systems enabling aesthetic experiences.....	54
4.2.9.	Noise attenuation.....	55
4.2.10.	Maintaining nursery populations and habitats.....	55
4.2.11.	Cultivated plants grown for nutrition, material, and energy purposes .....	55
<b>5.</b>	<b>Establishment of the pillars for the modelling and characterization of urban systems for NBS assessment .....</b>	<b>57</b>
5.1.	Urban NBS and urban systems under a combined approach.....	57
5.2.	Representation of urban systems.....	58
5.3.	Spatial and temporal levels .....	60
5.4.	Definition of urban system boundaries, urban types, and initial selection of indicators	62
5.4.1.	Urban system boundaries .....	62
5.4.2.	Urban Types .....	64
<b>6.</b>	<b>Representation of NBS and urban systems in the system dynamics modelling framework of WP4.....</b>	<b>69</b>
6.1.	Introduction to system dynamics models, MIMES and its adaptation to the study of urban systems.....	69
6.2.	Representation of NBS in the modelling framework .....	71

6.2.1.	NBS compartment .....	73
6.2.2.	Anthroposphere compartment.....	75
6.2.3.	Atmosphere compartment.....	76
6.2.4.	ES compartment .....	76
6.2.5.	Implementation compartment.....	76
6.3.	Representation of urban systems in the modelling framework .....	77
6.3.1.	Differences and similitudes with the NBS module .....	78
6.4.	Relationship between NBS and urban systems in the modelling framework.....	79
6.5.	Outlook on the SDM interoperability with the platform.....	81
<b>7.</b>	<b>Collection of data and initial evaluation of the modelling framework .....</b>	<b>82</b>
7.1.	Case studies .....	82
7.1.1.	Alcala de Henares .....	83
7.1.2.	Szeged .....	84
7.1.3.	Cankaya .....	86
7.1.4.	Metropolitan City of Milan.....	87
7.1.5.	NBS case studies provided by G4C .....	89
7.1.6.	NBS case studies provided by P&C .....	91
7.2.	Initial evaluation of the modelling framework.....	93
<b>8.</b>	<b>Evaluation based on expert knowledge.....</b>	<b>95</b>
8.1.	Priority urban ESs .....	95
8.2.	Urban system boundaries .....	96
8.3.	Temporal levels .....	97
8.4.	Urban typologies.....	97
<b>9.</b>	<b>Conclusions and outlook.....</b>	<b>98</b>
<b>10.</b>	<b>References.....</b>	<b>100</b>
	<b>Appendix I: Supplementary Material .....</b>	<b>123</b>

## List of Figures

Figure 1. Diagram of direct relations with Task 4.1 .....	15
Figure 2. Methodological steps, related actions and results .....	15
Figure 3. ES Cascade model from (La Notte et al., 2017). .....	17
Figure 4. Conceptualisation of NBS Types; elaboration after Eggermont et al. (2015). .....	30
Figure 5. Scales of the urban challenges and related NBS. ....	31
Figure 6. Built structure and water NBS archetypes for modelling purposes corresponding to MAES Level 1 land cover types. ....	32
Figure 7. Land NBS archetypes for modelling purposes corresponding to MAES Level 1 land cover types. ....	33
Figure 8. Scheme of urban sub-systems .....	60
Figure 9. Scheme of an urban region and its main components (Forman, 2014).....	61
Figure 10. MIMES framework (Boumans et al 2015). .....	70
Figure 11. Adaptation of the (a) MIMES framework to represent a generic (b) NBS module, composed by four main compartments: NBS, anthroposphere, atmosphere, ES, and implementation compartment. ....	72
Figure 12. Current representation of the woody plants submodel in SIMILE. ....	73
Figure 13. Current representation of the litter submodel in SIMILE. ....	74
Figure 14. Adaptation of the (a) MIMES framework to depict (b) an urban system module.....	78
Figure 15. Exchanges between (a) the NBS module and (b) the urban system module within the whole SDM. ....	80
Figure 16. Procedure for the integration of MIMES tool into the platform.....	81
Figure 17. (a) Edible forest, Alcalá de Henares (b) Urban park, Cankaya (c) Waterfront, Szeged (d) Quarry restoration, Metropolitan City of Milan. ....	82

## List of Tables

Table 1: Contribution of partners to D4.1.....	14
Table 2. Protocol adopted for the systematic literature review performed in Task 4.1; after Luederitz et al. (2015) and Brink et al. (2016).....	16
Table 3. Protocol of the systematic literature review .....	19
Table 4. UCs and USCs extracted from D2.1.....	21
Table 5. UCs and USCs identified from the literature review which relate to NBS.....	22
Table 6. UCs and USCs selected in the Task 4.1.....	23
Table 7. Relation of Urban Challenges to ES Class, Group and Section of CICES v 5.1.....	25
Table 8. . ES classes most assessed in the literature review. ....	26
Table 9. Selected ES and their prioritization in relation to UC and USC studied.....	27
Table 10. NBS Type 3 identified in the literature review and their relation to USCs.....	34
Table 11. Relation of selected NBS-ES-UCs (& USCs). ES classes refer to the CICES system (Haines-Young and Potschin, 2018).....	40
Table 12. List of environmental models used to identify factors influencing ecological processes. ....	41
Table 13. List of environmental models used to identify factors influencing ecological processes. ....	56
Table 14. Potential system boundary indicators. ....	63
Table 15. Potential system boundary indicators. ....	66
Table 16. Potential indicators for the city/metropolitan level. ....	67
Table 17. Potential indicators for the neighborhood/district level. ....	68
Table 18. Social, economic, and environmental datasets collected for Alcala de Henares. ....	83
Table 19. Social, economic, and environmental datasets collected for Szeged.....	84
Table 20. Social, economic, and environmental datasets collected for Cankaya.....	86
Table 21. Social, economic, and environmental datasets collected for the Metropolitan City of Milan.....	88
Table 22. NBS case studies of Metropolitan City of Milan. ....	89
Table 23. List of G4C case studies.....	90
Table 24. Environmental data of the NBS case studies of G4C.....	90
Table 25. List of P&C case studies.....	91
Table 26. Environmental datasets for the NBS case studies of P&C .....	92
Table 27. Comparison of the priority ES to be investigated. ....	96

## Glossary

<u>Acronym</u>	<u>Full name</u>
<b>CICES</b>	Common International Classification of Ecosystem Services
<b>D2.1</b>	Deliverable 2.1 (Nature4Cities) “System of integrated multi-scale and multi-thematic performance indicators for the assessment of urban challenges and NBS”
<b>EC</b>	European Commission
<b>EbA</b>	Ecosystem-based Adaptation
<b>EEA</b>	European Environment Agency
<b>ES</b>	Ecosystem Service(s)
<b>GI</b>	Green Infrastructure
<b>HAVC</b>	Heat, Air Ventilation, and Cooling
<b>IUCN</b>	International Union for Conservation of Nature
<b>LULC</b>	Land Use Land Cover
<b>MAES</b>	Mapping and Assessment of Ecosystems and their Services
<b>MEA</b>	Millennium Ecosystem Assessment
<b>MIMES</b>	Multiscale Integrated Modelling of Ecosystem Services
<b>NBS</b>	Nature-based Solutions
<b>NUTS</b>	Classification of Territorial Units for Statistics
<b>PET</b>	Physiological Equivalent Temperature
<b>SEEA</b>	System of Integrated Environmental-Economic Accounting
<b>SDM</b>	System Dynamics Model
<b>SME</b>	Small and Medium Enterprise
<b>SPE</b>	Service Providing Elements
<b>SPU</b>	Service Providing Unit
<b>SUDS</b>	Sustainable Urban Drainage Systems
<b>TEEB</b>	The Economics of Ecosystems and Biodiversity
<b>UC</b>	Urban Challenge
<b>UES</b>	Urban Ecosystem Service(s)
<b>USC</b>	Urban Sub-Challenge
<b>UE</b>	Urban Ecology
<b>UK NEA</b>	United Kingdom National Ecosystem Assessment
<b>UM</b>	Urban Metabolism
<b>UN</b>	United Nations
<b>UPE</b>	Urban Political Ecology
<b>USLE</b>	Universal Soil Loss Equation
<b>WFD</b>	Water Framework Directive
<b>WP</b>	Work Package





## Executive Summary

The mainstreaming of urban Nature Based Solutions (NBS) requires a better understanding of their economic benefits and co-benefits, contributing to the assessment of their sustainability, feasibility and advantages against traditional solutions. The most suitable and effective approaches to assess the sustainability of NBS are the ones that explicitly consider the technosphere and eco-sphere nexuses and quantify benefits and co-benefits through the valuation of urban ecosystem services.

In this context, the aim of Deliverable 4.1 is to define a system dynamics modelling framework at different spatial and temporal scales for assessing ecosystem services (ES) supplied by NBS designed to address specific challenges of urban environments. The modelling framework of any process-based model has to provide an adequate representation of the real system and generate accurate output behaviours. In this sense, the development and validation of system dynamics models requires the fulfilment of the following stages: (i) problem description and definition; (ii) system conceptualization; (iii) model formulation; (iv) validation and evaluation of structure and behaviour; and (v) implementation. The first three stages and initial works for the fourth stage were developed as part of this deliverable.

For the description and definition of the problem, an extended literature review was done to identify a large group of existing urban challenges, ES, and NBS and establish the links between these components. From that large group, a smaller set of urban challenges, ES, and NBS was selected for inclusion in the modelling framework. This selection was then followed by a revision of conceptual NBS frameworks, land management and ecological restoration techniques, which together with the work conducted in the Task 1.1 informed the development of an urban NBS typology for modelling purposes.

The system conceptualization and an initial model formulation was supported by the identification of the biophysical structures and socio-ecological processes related to the provision of the selected ES, following the ES cascade framework. This identification was based on the initial literature review, complemented by the review of studies investigating relations between structures and processes as well as studies describing existing ES process-based models. The review of these sources permitted the identification of main variables (input, intermediate variables and outputs) and processes to be considered in the system dynamics model and, together with the outputs from the Task 2.1, facilitated the identification of suitable proxy-parameters to use as ES indicators.

Moreover, it was also necessary to characterize the urban systems in which the NBS are developed. For this purpose, the urban system boundaries (primary and secondary) and urban typologies at different spatial levels (urban region, city/metropolis, and neighbourhood) were

identified via descriptive indicators, based on an integrated urban metabolism and urban ecology perspective. The metropolis/city level was identified as the primary system boundary, whilst the urban region level as the secondary one. The advantage of using a double system boundary perspective is related to the possibility to consider the dependency of the urban systems on their surrounding environment and the potential burden shifting. This characterization was supported by key references of urban sustainability, urban ecology and urban metabolism as well as a review of the grey and scientific literature on urban systems. The sets of descriptive indicators identified for urban system boundaries and urban typologies were narrowed down making use of two criteria: *easiness* (i.e. calculated from available data and without requiring specific tools or models), and *replicability* for different urban areas in Europe. Moreover, the selection of indicators for urban typologies favoured those indicators adequate for all or several of the spatial levels against others, ensuring consistency among different levels and ultimately obtaining a reduced core set of indicators.

Based on the previous stages, an initial representation of NBS and urban systems in modelling framework was developed by extending and adapting the Multiscale Integrated Model of Ecosystem Services (MIMES) to urban systems, providing the model conceptualization and an initial model formulation. MIMES is built using a system dynamics approach and was originally developed for regional studies. This modelling framework is capable of representing complex systems, such as coupled human and natural systems including their exchanges and feedbacks. Designing a modelling framework of NBS and urban systems via the MIMES approach therefore allowed to acknowledge the behaviour of these complex systems and better informing on the cost-effectiveness of urban NBS in a more realistic form.

A first evaluation of the model structure was done making use of data gathered from pilot cities and small and medium enterprises, which assessed the availability of input variables considered for the model, including their adequate temporal and spatial resolution, and helped to understand if substantial modifications to the initial modelling framework were required. A second evaluation of the structure of the model was supported on expert knowledge gathered through a workshop with external advisors. This double evaluation permitted to understand that there is a lack of data available for the urban systems across the pilot cities and their sites of intervention, which may jeopardise the development of the model, their testing, and calibration. Nevertheless, it assisted in the refinement of the urban system boundaries, served to test the interest of the definition of urban typologies at different spatial levels, and allowed the definition of a modelling temporal scope for the models.

The main output of Deliverable 4.1 is the definition of a system dynamics modelling framework for assessing ES supply by urban NBS that can inform their effectiveness for addressing main challenges of urban systems. In order to do so, two main modules were defined following the MIMES approach: NBS module and urban system module. The NBS module focuses on the calculation of ES as final outputs, also considering changes in the consumption of materials and

energy to inform the impact of certain ES (e.g. the impact of the regulation of temperature and humidity in the consumption of energy). In contrast, the urban system module aims to understand how the supply of ES by NBS could affect the urban metabolism by modifying the demand of materials and energy.

For the development of this modelling framework, an extended literature review was further performed, which constitutes a second valuable output of the present Deliverable. This work of review allowed to identify urban challenges directly related to NBS based on the works of D2.1, and supported the selection of an ES classification system (i.e. CICES) with ES classes that can be linked to specific urban challenges. Moreover, the study of the literature could suggest how to adapt the NBS typology of the Task 1.1 for modelling purposes, and assisted the selection of NBS types able to provide the ES, which are relevant for the future integrated assessment of the case studies proposed by the pilot cities (WP7).

A third output worth mentioning is the identification of the main processes and biophysical and social factors influencing the supply of ES. These helped to define parameter proxies for the selected ES classes (outputs of the model), and the main compartments, submodels, relations, and assumptions underpinning the system dynamics NBS module based on MIMES.

Additionally, the modelling framework, the selected ES classes and their parameter proxies provide a basis for the current development of an economic assessment scale (Task 4.2) to monetarise the values of ES provided by NBS, which can be compared with the NBS life cycle costs.

Finally, this report shows that a knowledge gap still exists regarding the explicit relationship among biophysical structures, processes and supply of ES. It also highlights that there is a lack of environmental, economic and social data for urban systems which could hamper the development of system dynamics models for assessing cost-effectiveness of NBS, but also for those assessing urban sustainability at high temporal and spatial resolution. This implies that further efforts are required to develop methods for easy data collection, which would minimise the impact that data scarcity could have in the implementation of future system dynamics models.