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Using a system thinking approach to assess the contribution of nature based solutions to sustainable development goals

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HIGHLIGHTS

- Evidence regarding the contribution of NBS to SDGs is needed.
- Understanding the dynamic evolution of co-benefits increases NBS effectiveness.
- The capacity of NBS for addressing SDGs is highly dependent on NBS multifunctionality.
- Engaging stakeholders in the first stages of NBS design and implementation is key.

GRAPHICAL ABSTRACT

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ABSTRACT

Climate change and the overexploitation of natural resources increase the need to integrate sustainable development policies at both national and international levels to fit the demands of a growing population. In 2015 the United Nations (UN) established the 2030 Agenda for sustainable development with the aim of eradicating extreme poverty, reducing inequality and protecting the planet. The Agenda 2030 highlights the importance of biodiversity and the functioning of ecosystems to maintain economic activities and the well-being of local communities. Nature Based Solutions (NBS) support biodiversity conservation and the functioning of ecosystems. NBS are increasingly seen as innovative solutions to manage water-related risks while transforming natural capital into a source of green growth and sustainable development. In this context, NBS could potentially contribute to the achievement of several Sustainable Development Goals (SDGs) by promoting the delivery of bundles of ecosystem services together generating various social, economic and environmental co-benefits. However, to achieve the full potential of NBS, it is necessary to recognize the trade-offs and synergies of the co-benefits associated with their implementation. To this aim, we have adopted a system perspective and a multi-sectoral approach to analyse the potential of NBS to deliver co-benefits while at the same time reducing the negative effects of water-related hazards. Using the case study of Copenhagen, we have analysed the relationships between the co-benefits associated with the scenario of the restoration of the Ladegaardsaa urban river. Our hypothesis is that enhancing the understanding of the social, economic and environmental factors of the system,

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including mutual influences and trade-offs, could improve the decision-making process and thereby enhance the capability of NBS to contribute to the achievement of the SDGs.

1. Introduction

Climate change and the overexploitation of natural resources have increased the need to integrate sustainable development policies at both national and international levels to fit the demands of a growing population (Colglazier, 2015). The potential contribution of ecosystems for dealing with societal challenges has been increasingly emphasized in the frame of global agendas such as the Sendai Framework for Disaster Risk Reduction (United Nations, 2015), the Strategic Plan for Biodiversity (Secretariat of the Convention on Biological Diversity, 2010) or the 2030 Agenda for Sustainable Development. The latter was agreed on in 2015 by the United Nations with the aim of eradicating extreme poverty, reducing inequality and protecting the planet. The agenda contains 17 Sustainable Development Goals (SDGs) which are areas of intervention that are needed to achieve sustainable development (Colglazier, 2015). It stresses the importance of sustainable management of natural resources and the functioning of ecosystems to maintain economic activities and well-being of local communities. Indeed, biodiversity and ecosystems predominate directly in many of the SDGs and their associated targets. For example, SDG 14 highlights the importance of protecting oceans, seas and marine resources to achieve sustainable development (Faivre et al., 2017).

To accomplish the 2030 Agenda, new initiatives and strategies aiming at enhancing and protecting ecosystems and their services have become the core of action to be developed, i.e. Ecosystem-based Adaptation, Green Infrastructure, Ecosystem-based Disaster-Risk Reduction or Natural Water Retention Measures (Faivre et al., 2017; Munang et al., 2013; Schäffler and Swilling, 2013; Cohen-Shacham et al., 2016). Among all these approaches, the concept of Nature Based Solutions (NBS) is increasingly seen as a key component in the mainstreaming of nature in development of policies and actions. The term NBS is often used as an umbrella concept, embedding a wide range of conservation and sustainability measures (Seddon et al., 2019). NBS are defined by the European Commission as:" …living solutions inspired by, continuously supported by and using nature, which are designed to address various societal challenges in a resource-efficient and adaptable manner and to simultaneously provide economic, social, and environmental benefits" (Maes and Jacobs, 2017). This definition highlights the importance of natural capital in the process of building a sustainable society supported by a green economic system. The key characteristic of NBS is their capability to be multi-functional, which means the ability to simultaneously perform multiple functions to deliver a set of associated ecosystem services (ES). The premise of the NBS approach is that enhancing and protecting certain ecosystems may buffer the unfavourable impacts of climate change while providing multiple environmental, economic and social co-benefits. For example, green alleys or tree planting have proven to be an effective approach to manage storm-water by retention and subsequent evaporation or infiltration while at the same time providing multiple co-benefits, such as groundwater recharge, urban heat island reduction, and expanded wildlife habitat (Newell et al., 2013). Socio-ecological systems, in which NBS are usually implemented, are dynamically complex, governed by non-linearities, feedback loops and multiple interconnections constantly changing over time (Nuno et al., 2014). Different policy interventions or management regimes may directly or indirectly affect different elements of the system causing trade-offs and synergies among co-benefits. For example, policies designed to protect a coastal ecosystem may improve its ecological status, but might also lead to a decrease of coastal livelihoods. Moreover, NBS may be altered over time as a result of the dynamic evolution of their natural component or due to responses to external pressures such as climate change. Consequently, the interconnections among co-benefits may also evolve over time. This means that trade-offs and synergies should be framed as an inter-temporal issue that manifest overtime (Qiao et al., 2019; Gómez Martín et al., 2020). The identification of synergies and trade-offs among co-benefits may reveal unconsidered consequences of diverse management strategies. This could support in finding the balance between social, economic and environmental targets (Calliari et al., 2019; Haase et al., 2012). In this paper, we argue that understanding the dynamic evolution of trade-offs and synergies across co-benefits may facilitate management to maintain synergies and thus, NBS multifunctionality may be enhanced and lead to increased adaptive capacity of NBS for addressing SDGs. To this aim, the complex structure of the system interested or impacted by NBS implementation is investigated and analysed.

Using the urban river restoration project in Copenhagen city as a means to demonstrate the framework of our analysis, we have assessed the trade-offs and synergies of the co-benefits associated with potential NBS implementation and thus with related SDGs. The urban river restoration project is a scenario for climate adaptation and greening the city of Copenhagen but not yet politically approved and implemented by the involved municipalities. We have adopted a system thinking approach to understand the main dynamics between NBS and their co-benefits to investigate the long-term effects on different SDGs. We have developed a Fuzzy Cognitive Map (FCM), a knowledge-based methodology developed to simulate and model dynamic systems (Kosko, 1986). In this case it was used to conceptualize and understand the social-ecological system where the scenario of a river restoration will be applied to analyse key relationships and feedback loops between the potential co-benefits that this NBS may deliver. The FCM was co-produced along with stakeholders and experts of the system where NBS could be applied. Participatory modelling was used to obtain relevant bottom-up information and to organize the collective knowledge of stakeholders in a Causal Loop Diagram (CLD) while promoting a constructive discussion among stakeholders. CLDs have been widely used as a graphical tool to represent the feedback structure of systems and to easily capture the causes of dynamics (Sterman, 2000). The CLD co-developed represents the shared vision of stakeholders of the system and it was used to set the basis for the FCM development. Although FCMs are not able to make quantitative predictions, they are suitable to easily indicate changes in the patterns of behaviour of the system due to changes in the relationships between factors. Therefore, FCMs allow the prediction of the effects of different policies taken under "what-if" scenarios. However, traditional vector-matrix operations typical from FCM assume that all the processes occur at the same time. It considers that the strength of the relationships between variables are constant over time. This structure limits the realistic description of the dynamics between co-benefits. To overcome this drawback and to improve the description of the non-linear behaviour of complex systems we implement the semi-dynamic FCM-based approach described in (Giordano et al., 2020). This work proposes the inclusion of time delays in the matrix-structure of FCM by allowing changes in the adjacency matrix, further explained in 2.3.

2. Research and methods

2.1. Case study

In December 2009, the fifteenth session of the Conference of the Parties (COP 15) was held in Copenhagen, Denmark. The objective of the COP 15 was to enter into a binding global climate agreement that includes as many countries as possible in order to reduce greenhouse emissions. As a result of COP 15, the City of Copenhagen developed the Copenhagen Climate Adaptation Plan in 2011. This plan established the framework needed for the implementation of climate adaptive measures in the city administration area. It is highly likely that the frequency and intensity of rainfall and cloudburst events in Denmark and Copenhagen will increase during fall and winter (City of Copenhagen, 2012; Liu and Jensen, 2017), thus contributing to the rise of shallow groundwater level and increase the risk for groundwater flooding causing economic and human costs. The catastrophic cloudburst event in July 2011 boosted the development of the Cloudburst Management Plan in 2012 making the Climate Adaptation Plan more explicit in this regard. This plan defines priority actions to reduce the negative impact of high-intensity rain.

Within the cloudburst management plan, different NBS were selected to mitigate the negative effects of pluvial flooding i.e. construction of green spaces and cloudburst channels, where the first include retention and detention areas to store excess rainwater for either infiltration or evaporation. The latter include channels that route excess water to open water recipients further downstream. In this paper, the focus is on the restoration of an urban river (the Ladegaardsaa) as a scenario for an NBS. According to the cloudburst management plan, NBS can be beneficial for drainage and for ensuring a sustainable river discharge. Currently, the Ladegaardsaa river is part of a larger piped river system (see Fig. 1) further upstream. The restoration of the river is a scenario which is part of a larger project including a traffic component, which consists of removing the present flyover motorway in combination with short and long tunnels to replace parts of existing roads further down the line. In addition to this, and considered in this paper, is the scenario of restoring the piped urban river and the further development into an open river park with both green and blue areas. The urban river scenario would restore the natural flow route towards the artificial lakes (shown in Fig. 1). The main objective of this NBS is to improve the drainage capacity of the city, thus mitigating groundwater flooding and subsequent damage to underground built infrastructure, notably cellars. Additionally, this NBS is expected to deliver a number of co-benefits (i.e. pollution reduction, heat island reduction, health and wellbeing, GHG reduction and green jobs creation) which could potentially contribute to the achievement of several SDGs.

2.2. Participatory modelling phase

Participatory modelling supports the decision-making process by enabling the integration of key stakeholders in the co-creation of conceptual models and co-design of actions and strategies. It also supports the active collaboration and the rigorous integration of different expertise and interdisciplinary skills, thus building greater trust in models (Zomorodian et al., 2018). The key advantage in the field of NBS analysis (with specific focus on decision support) relies in its potential for integration of variables (e.g. qualitative and quantitative), knowledge (e.g. expert and derived from models) and issues (e.g. social, environmental, economic, etc.). This is, indeed, highly relevant for describing the multi-dimensionality of NBS, and their capability to produce a multitude of

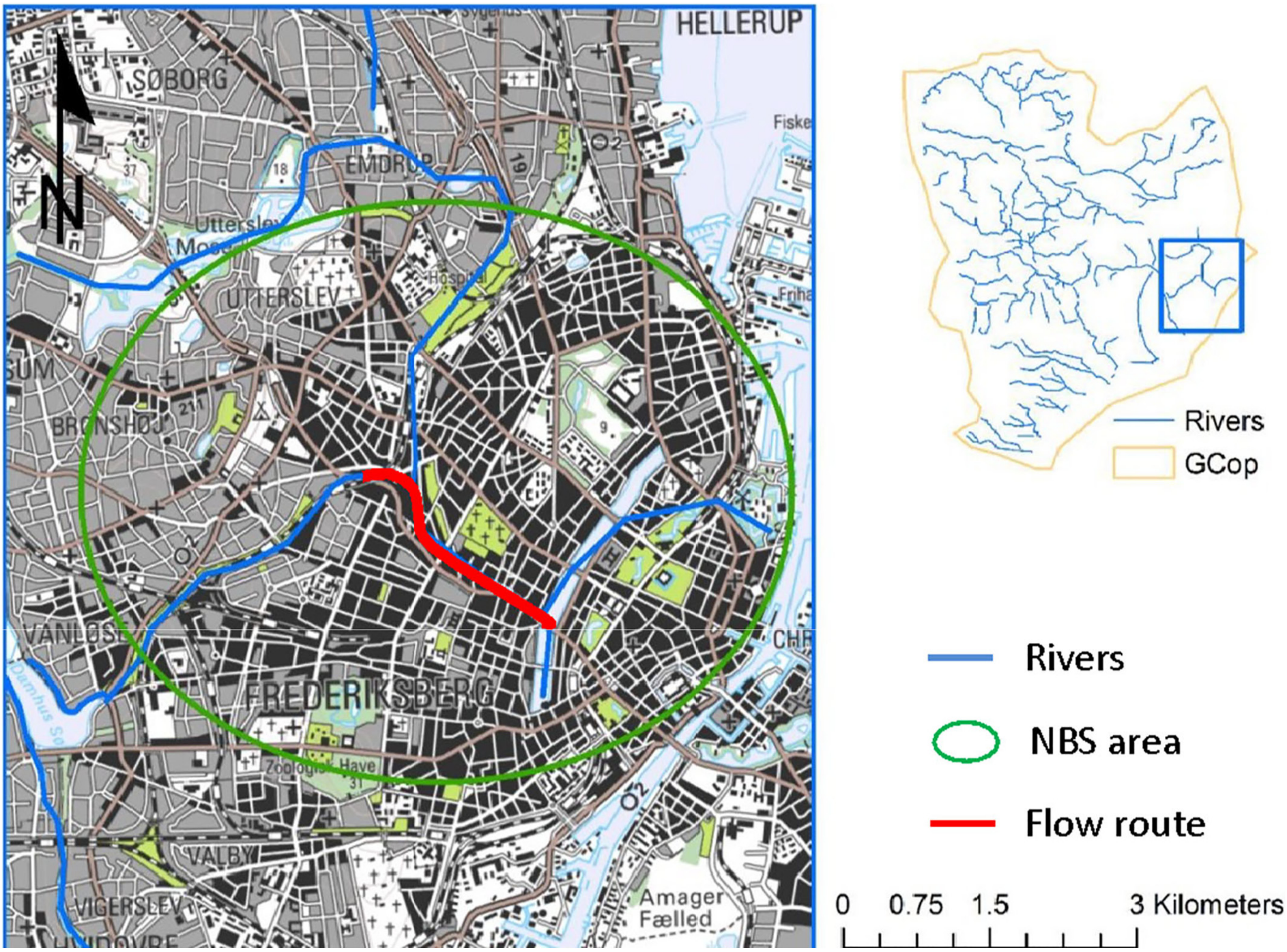

Fig. 1. NBS area: potential restored urban river (red) and its tributaries (blue) and surrounding catchment (to the right). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

benefits over time. Participatory modelling is particularly well-suited for obtaining data coming from formal and non-formal sources. In this study, participatory modelling has been used to develop a comprehensive understanding of the scope of the system and to guide the actions undertaken, while showcasing advantages at both individual and collective levels. At the individual level, the approach improves the problem formulation and perception of participants. At the collective level, it allows their alignment, the achievement of a consensus with respect to decisions and the involvement of the group with respect to these decisions. We have divided the participatory process into two phases. During the first phase, a Causal Loop Diagram (CLD) defining relationships among the main variables of the system was developed using group model building techniques (Vennix, 1999). In the second phase, some quantitative elements of the FCM were assigned to the CLD by experts (i.e. link weights and time delays). To increase the effectiveness of NBS implementation and to assess the associated co-benefits, it is necessary to understand who is affected by the restoration scenario of the Ladegaardsaa urban river. It is also important to understand who has the power to influence the results obtained by executing the NBS, i.e. Danish Regions, municipalities, water utility companies, Danish Regions and others. The stakeholder group was representative for the different levels of governance and knowledge and has been carefully selected to avoid unnecessary overlap and missing elements. The selection was made in a way that the largest number of perceptions of the system was collected. The 'snowballing' technique was used to update the list, thus involving all the potentially relevant stakeholders that were cited or mentioned during the process. The number of stakeholders was chosen for having a realistic representation of the system and to allow for the active participation of individuals during the group model building exercise (See Appendix A of the supplementary material). In concordance with previous studies we estimated that the desired number of participants to successfully perform the group model building exercise ranged between 7 and 15 participants (Videira et al., 2014).

2.3. Group model building: Fuzzy cognitive maps development

Fuzzy Cognitive Maps (FCM) are based on graph theory and were introduced the first time by Bart Kosko (Kosko, 1986). They have been widely used to address complex problems from climate change adaptation to landscape or forest management (Martinez et al., 2018). FCM are graphical representations of causal relationships among concepts, also known as factors, variables or nodes in a system. The relationships are represented with links connecting the concepts. The direction of the causal relationship is represented with a positive or negative symbol. A positive sign (+) is used to represent positive causal relationships between two concepts or variables. This means that the decrease/increase of a variable V_i leads to a decrease/increase of variable V_j. A negative symbol (−) is used to represent negative causal relationships which indicates an inverse relationship (a raise in variable V_i will reduce variable V_j and vice versa). To indicate the strength of the causal relationship (weak, medium, strong) a weight that takes a normalised value between [−1,1] is assigned to each link (Sokar et al., 2011). This structure allows the propagation of the causality backward and forward allowing the knowledge base to increase when the concepts and links between them increase (Kontogianni et al., 2012).

FCMs are easy to build and easy to understand by non-technical experts, facilitating debate among stakeholders and the co-creation of shared knowledge. Additionally, its vector-matrix structure facilitates the aggregation of different experts and stakeholders' views. For this reason, FCMs have gained considerable interest in the research community to be combined with stakeholder's engagement and participatory modelling exercises (Gray et al., 2015). There are different participatory modelling approaches i.e. mediated modelling, shared vision planning, participatory simulation, companion modelling or participatory mapping among others (Chambers, 2006; Diehl, 1992; Simon and Etienne, 2010; Voinov and Bousquet, 2010; Williams et al., 2019). Unlike participatory processes carried out at the individual level (i.e. individual interviews) which are usually implemented to analyse differences in perception, Group Model Building (GMB) techniques pursue a shared understanding of the problem to be addressed. In this study, GMB was used to facilitate the consensus agreement process and to increase the communication and shared vision among stakeholders, as well as to enhance confidence among stakeholders in the use of system ideas. It was also used to conceptualize and understand the socio-environmental system in which the NBS will be applied**.** The GMB process was carried out in a two-hour workshop with key stakeholders of the system. During the process, stakeholders contributed to the identification of key factors and issues relevant for the modelling of the NBS. During the process, the moderator adapted the exercise to stimulate the exchange of relevant local knowledge among the participants. To facilitate the development of the Causal Loop Diagram (CLD), a syntactic rule was used to represent the key variables within the model. The participants were asked to use cards of different colours to represent the different variables and factors within the system. The variables representing natural resources and ecosystem services were marked in green, blue cards were used to identify socio-economic factors, yellow cards represented all the activities or actions. Finally, all the barriers, risks or challenges were marked in red. The stakeholders were also asked to represent and to mark the relationships between variables and their polarity (positive or negative). During the Group Model Building (GMB) session, discrepancies between participants or differences of opinion may arise. Whenever possible, consensus among participants was reached. For this, the role of the facilitator was crucial to favour the elucidation of knowledge within the group and to reveal hidden assumptions and differences among participants, thus facilitating a consensus view of the problem. In those occasions when it was not possible to reach an agreement, the final decision was taken by the expert group. To ease the post-processing of the Causal Loop Diagram, the resulting model was digitized using Vensim software.

The group model was analysed and post-processed by a group of experts who were involved in the GMB process and with experience in the system and in the FCM development. During the post-processing exercise, missing variables relevant for the co-benefit assessment were added into the model. The expert group was also in charge of indicating the strength of impacts of the elements composing the map. The weight assigned was used to describe the strength of the relationships (weak, medium, strong) between variables or nodes. The strength of a relationship was represented by changing the thickness of the links between concepts composing the FCM (See Fig. 2). The experts also suggested 'delays' (with a //) to represent processes or decisions that require some time to occur. This was made to allow a semi-quantitative analysis of the temporal dynamics. To ease the visualization of the causes-effects

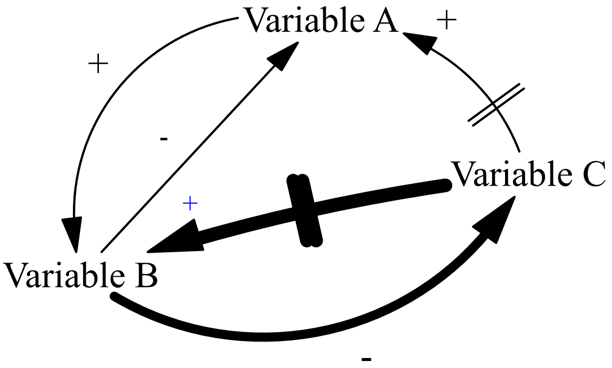

Fig. 2. Simple FCM. The thickness of the arrows indicates the strength in the relationship. Positive and negative symbols indicate the polarity of the relationship. Delays are indicated with two lines crossing the links (//).

of the processes occurring in the system, important feedback loops were identified within the system. The polarity of the loop is dependent on the polarity of the links composing the loop, in turn determining the behaviour of the variables within the loop. A reinforcing or positive loop (R) results when an action produces a result which influences the initial action. This type of loop results in exponential growth or decline. Alternatively, a balancing or negative loop (B) occurs when an action is taken to change the current state of a variable to a desired state. This type of loop tends to produce oscillations or movement towards equilibrium (Sterman, 2000).

After the participatory modelling phase, each fuzzy weight (weak, medium, strong) was translated into a numerical value. The weights ranged in an interval of {−1,0,1}. The value 1 represents a positive causality and the strongest relationship. The closer the values approach 0, the weaker the relationships are. For weak relationships, a value of 0.3 was assigned. For relationships of medium strength, a value of 0.6 was given. Finally, value 1 was used for the strongest links.

The first step to transform the Causal Loop Diagram into a Fuzzy Cognitive Map (FCM) was to translate the weights of the relationships into an adjacency matrix. This matrix defines the structure of the FCM and is needed to establish the dynamic inferences. The FCM is simulated using the mathematical formulation developed by Kosko (Kosko, 1986) and expressed in Eq.

$$x_i(t) = f\left(\sum_{\substack{j=1 \\ j\neq i}}^{n} x_j(t-1)w_{ij}\right) \tag{1}$$

where $x_i(t)$ is the value of variable V_i at time t, $x_j(t-1)$ is the value of variable V_j at time $t-1$ and w_{ji} is the weight of the relationship between the variable V_i and variable V_j. Finally, f represents a threshold function that is used to normalize the values of the FCM variables in an interval [−1,1].

As previously stated, traditional FCM does not allow for consideration of delays in the causality assuming that all the processes occur at the same time. The adjacency matrices produced are constant and assume that the polarity and the weights do not change over time (Papageorgiou and Salmeron, 2013). However, it should be considered that Nature Based Solutions (NBS) require time for becoming fully effective. Additionally, different co-benefits can be produced at different time steps (Giordano et al., 2020). To overcome this limitation and to describe the dynamics of the system to better represent "reality" we have introduced delays in the FCM allowing changes in the adjacency matrix and assuming that the weight can change over time. Following the work done by Giordano et al. (2020), we have developed three different adjacency matrices describing the strength of the casual connections at three different time steps (short term, medium term and long term). The FCM calculation described (Eq. 1) was sequentially implemented using the three adjacency matrices. The variable states resulting in the three-time steps were plotted in order to obtain the dynamic evolution of the FCM variables. For more information see Supplementary material in Appendix B.

2.4. FCM analysis

The analysis of the model has been carried out in two parts. First, the description of the qualitative model and the identification of feedback loops have been used to enhance the understanding of what drives the dynamic behaviour of the system. We assume that the dynamic behaviour of the system can be inferred from the structure and complex relationships of the diagram. Secondly, different "what-if" scenarios were simulated (Kok, 2009) to determine the state of the system under different conditions, such as e.g. the long-term effectiveness of NBS as well as the dynamic evolution of the co-benefits produced by different combinations. The simulation scenarios were defined and agreed among authors previously to the stakeholder workshop.

In this paper the following scenarios are considered: the restoration of the piped urban river combined with the creation of an urban green park (NBS1) and the creation of an urban green park without the river restoration (NBS2). Additionally, two soft measures combined with the above mentioned NBS were simulated. NBS1 with green space management (NBS1-GSM) and with strong institutional collaboration (NBS1-GSM and IC) and NBS2 with green space management (NBS2-GSM) and with strong institutional collaboration (NBS2-GSM and IC). Finally, a business as usual scenario without any measure applied has also been simulated (BAU).

To complete the study, the SDGs that could be potentially affected by NBS1 and NBS2 implementation have been identified. The co-benefits that are more likely to contribute to the achievement of each SDG have also been indicated. The long-term performance of each co-benefit under the 6 different NBS scenarios has also been highlighted (NBS1, NBS1-GSM, NBS1-GSM-IC, NBS2, NBS2-GSM and NBS2-GSM-IC). To ease the visualization of the results, a table describing which co-benefits affect each goal has been produced. For each scenario the long-term performance of each co-benefit has been indicated following a colour syntax. Red colour is used to indicate a weak contribution of the co-benefit to the achievement of a goal, orange is used when its contribution is moderate and green when the presence of a co-benefit significantly enhances the likelihood of achieving this goal.

3. Results

3.1. Qualitative analysis of the Fuzzy Cognitive Map (FCM)

In the following section, the system is presented as perceived by stakeholders, as well as the main patterns of behaviour which have been identified. Fig. 3 shows the FCM developed by stakeholders and experts. It is composed of key concepts (nodes) representing the economic, environmental and social factors of the system and their relationships. It describes system complexity and shows the multiplicity of interconnections among variables. To have a clearer representation of the loops, see Appendix C of the supplementary material.

The frequency and intensity of extreme weather events is highly influenced by climate change. An increase of the cloudburst events and prolonged rainfall in fall and winter will in the long-term, increase ground water level. This may increase the occurrence of groundwater flooding leading to an increase of water entering the sewer system. Stakeholders also perceived surface urban flooding as an important risk to consider. Surface flooding is aggravated by the water pushed up from the sewer system which cannot cope with excess water. Surface and groundwater flooding have a negative impact on Copenhagen wealth due to the damage caused by flooding and increased wastewater treatment. The re-connection of the river (which is currently piped) with groundwater is perceived to have a strong impact on groundwater flooding by increased drainage capacity. The re-naturalization of the river may reduce groundwater level and thus groundwater flooding. The restored urban river could receive water from cloudburst management plan associated NBS and thereby increasing the river discharge. Connecting the restored river would also improve the environmental quality of the connected lakes by maintaining an adequate water level which in turn, will contribute to reduce the urban heat island effect. We refer to NBS1 when the restoration of the river is combined with an adjacent urban green area in order to boost the delivery of ecosystem services. According to stakeholders, the green area on its own (NBS 2) may reduce surface urban flooding and provide a number of co-benefits such as biodiversity enhancement, reduction of the heat island effect or increase of the aesthetic value. However, the functionality of both NBS and thus, their effectiveness may be compromised by an

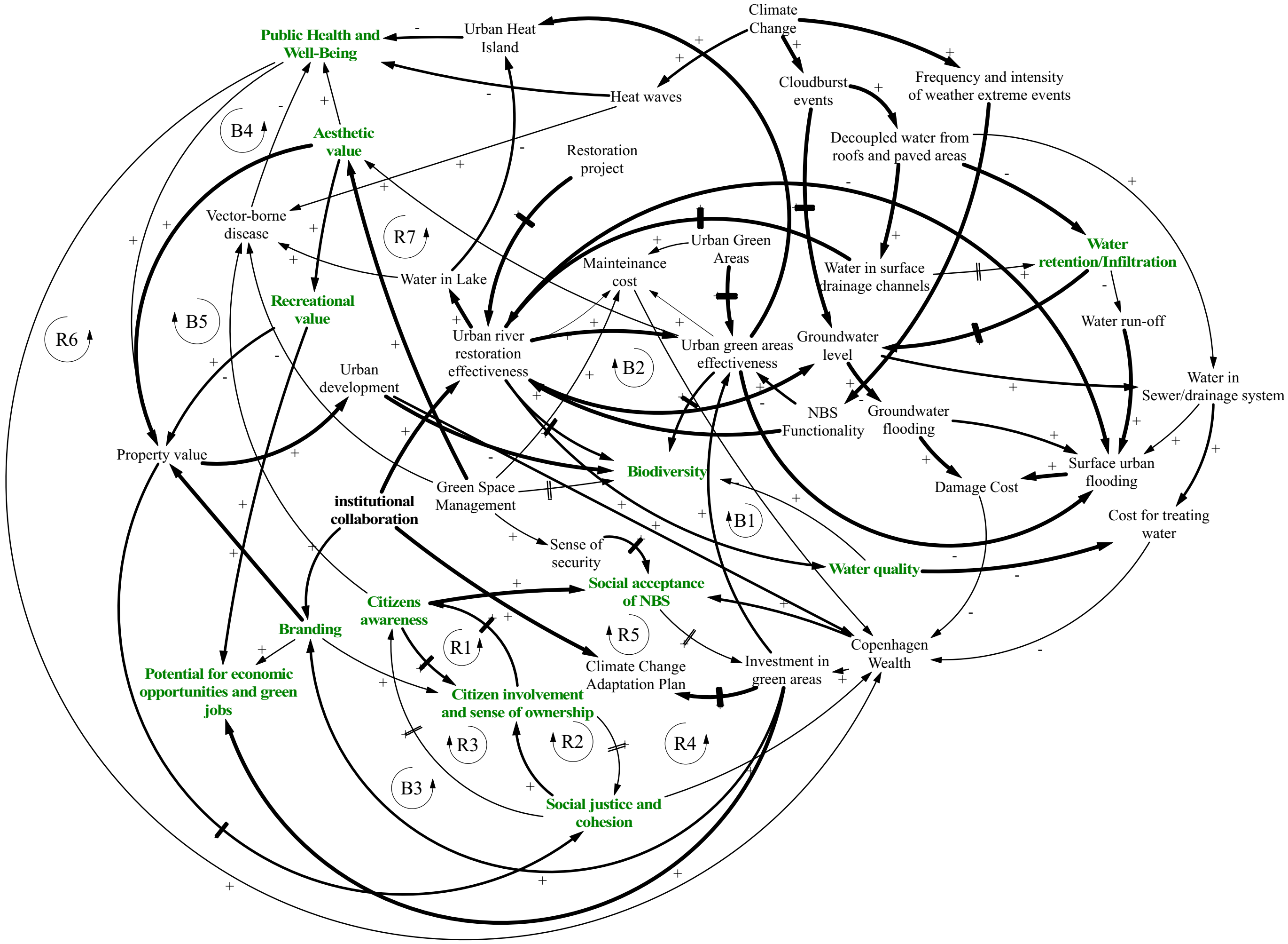

Fig. 3. Showing the final FCM integrating stakeholders and expert's knowledge. Note: Colour should be maintained when printed.

increase in the frequency and intensity of extreme weather events. Climate change may also increase the incidence of heat waves and thus the occurrence of vector-borne diseases.

Both NBS are perceived to have a positive impact on Copenhagen wealth. An effective river restoration would decrease the amount of water in the sewer system (by draining shallow groundwater) and therefore the economic cost associated with water treatment would decrease. Both NBS reduce damage cost associated with flooding and increase the potential for economic opportunities and green jobs in the area where the NBS is applied. To guarantee a continuous delivery of ecosystem services from the NBS, continuous management including maintenance and therefore, economic investments are required. This may have a negative effect on Copenhagen wealth (B1). Conducting a regular and appropriate management is perceived to be an important variable needed to support the social acceptance of NBS (B2). An increased acceptance of NBS may indirectly affect the aesthetic value of the area (B3) which in turn positively reinforces the delivery of other co-benefits such as public health and well-being or recreational value (R6, R7). Stakeholders also perceived institutional collaboration and investment in green areas as key factors to achieve the objectives established in the Copenhagen Climate Change Adaptation Plan. Finally, institutional collaboration involving key stakeholders, most notably municipalities and water utilities, and investment in green areas are needed to increase city branding, referring to local identity and the balance between human and nature. An enhancement in the branding the city's green image may increase citizen involvement and sense of ownership. Moreover, it could increase the potential for economic opportunities and green jobs by increasing the attractiveness of the city (R4 and R5).

According to the qualitative interpretation of the FCM co-benefits such as public health and well-being, aesthetic and recreational value may produce trade-offs with other co-benefits due to the causal connection that exists between these co-benefits and real estate property value. An increased value of the properties may support urban development which could negatively affect biodiversity. An increase in property value may also negatively affect social justice and cohesion (B4 and B5). Besides, social-justice and cohesion are strongly linked through reinforcing loops (R1, R2, R4 and R5) to other co-benefits such as citizen awareness, citizen involvement and sense of ownership and social acceptance of NBS. For this reason, a decrease of social justice may cause a chain reaction and reduce other associated co-benefits.

3.2. Semi-quantitative analysis of the dynamic behaviour of co-benefits

We only consider an NBS effective when the delivery of social, environmental and economic co-benefits is balanced. Therefore, we assume that an effective NBS implementation is based on reduction of trade-offs among co-benefits. From the modelling point of view, this means that if the increase of a certain co-benefit (i.e. aesthetic value) decreases the delivery of other co-benefits (i.e. social justice and cohesion) the effectiveness of this NBS will be reduced. A decrease in NBS effectiveness may have an impact on other co-benefits that are dependent on it.

Moreover, we have to consider that NBS may require time to be effective. This is well represented in Fig. 4 (A-B) which shows the dynamic behaviour of NBS effectiveness under different scenarios. When we compare the results of the scenarios, we observe that in the long term, NBS effectiveness is higher in scenarios NBS1 (river restoration combined with urban green park) and NBS1-GSM (river restoration combined with urban green park and good green space management), whereas NBS effectiveness is reached much earlier in scenarios NBS2-GSM-IC (urban green park with good green space management and strong institutional collaboration) and NBS1-GSM-IC (river restoration combined with an urban green park and with good green space management and strong institutional collaboration). This means that in order to accelerate the capability of NBS to deliver co-benefits, it is necessary to combine NBS with additional measures such as green space management or strong institutional collaboration. The results show that the restoration of the river combined with the urban green area (NBS1) is likely to reduce surface and groundwater flooding to a greater extent in the long term. However, the capability of NBS1 to reduce surface and groundwater flooding is very low in the first stages of NBS implementation. The implementation of the urban green area (NBS2) without green space management or institutional collaboration hardly has an impact on flood reduction. The results also show that when the NBS is combined with strong institutional collaboration, surface and groundwater flooding is reduced earlier (See Fig. 4 C-D). The capability of both NBS to reduce floods increases when the NBS is combined with strong institutional collaboration. Strong institutional collaboration does not directly influence the capability of NBS to cope with floods, but it does on the capability to deliver other co-benefits and thus, on its effectiveness.

Stakeholders perceived climate change as a limiting factor of NBS effectiveness. The results show that the frequency and intensity of extreme weather events are likely to reduce NBS functionality in the long term and thus NBS effectiveness, reducing the capability of NBS to cope with risk and to deliver co-benefits.

Climate change is expected to increase the occurrence of heat waves which may have direct consequences on public health and well-being. This could be aggravated by the urban heat island effect. The reduction of the latter was pointed out by the stakeholders as an important NBS co-benefit. The results of the simulation show that NBS1 is more effective in reducing urban heat island effect. However, the implementation of NBS1 with appropriate green space management and effective institutional collaboration accelerate the delivery of this co-benefit considerably. The results also show that the effectiveness of NBS2 in reducing heat island effect is highly dependent on green space management and institutional collaboration.

Fig. 5 shows four closely linked co-benefits; aesthetic value, recreational value, city branding and potential for economic opportunities and green jobs. The results of the simulation indicate that the implementation of NBS would rapidly increase the aesthetic value of the area and thus its recreational value.

In the long-term this would benefit the potential for economic opportunities and green jobs. The increase of the attractiveness of the city produced by the co-benefit of branding also has a positive impact on the potential for economic opportunities and green jobs. This is well illustrated in the similar patterns of behaviour that both co-benefits present. Once again, the results of the simulation demonstrate that the restoration of the urban river integrated with an adjacent green area (NBS1) is more effective in delivering these co-benefits. The simulations also demonstrate that green space management is essential to accelerate the delivery of aesthetic and recreational value co-benefits. If green space management is not applied, NBS requires more time to deliver these co-benefits.

The results of the simulation show a progressive decline in social justice and cohesion in scenarios NBS2-GSM-IC, NBS1-GSM-IC and NBS1-GSM (See Fig. 6 A).

This result exposes the trade-off that exists among social justice and cohesion, and aesthetic and recreational value. The increase of the

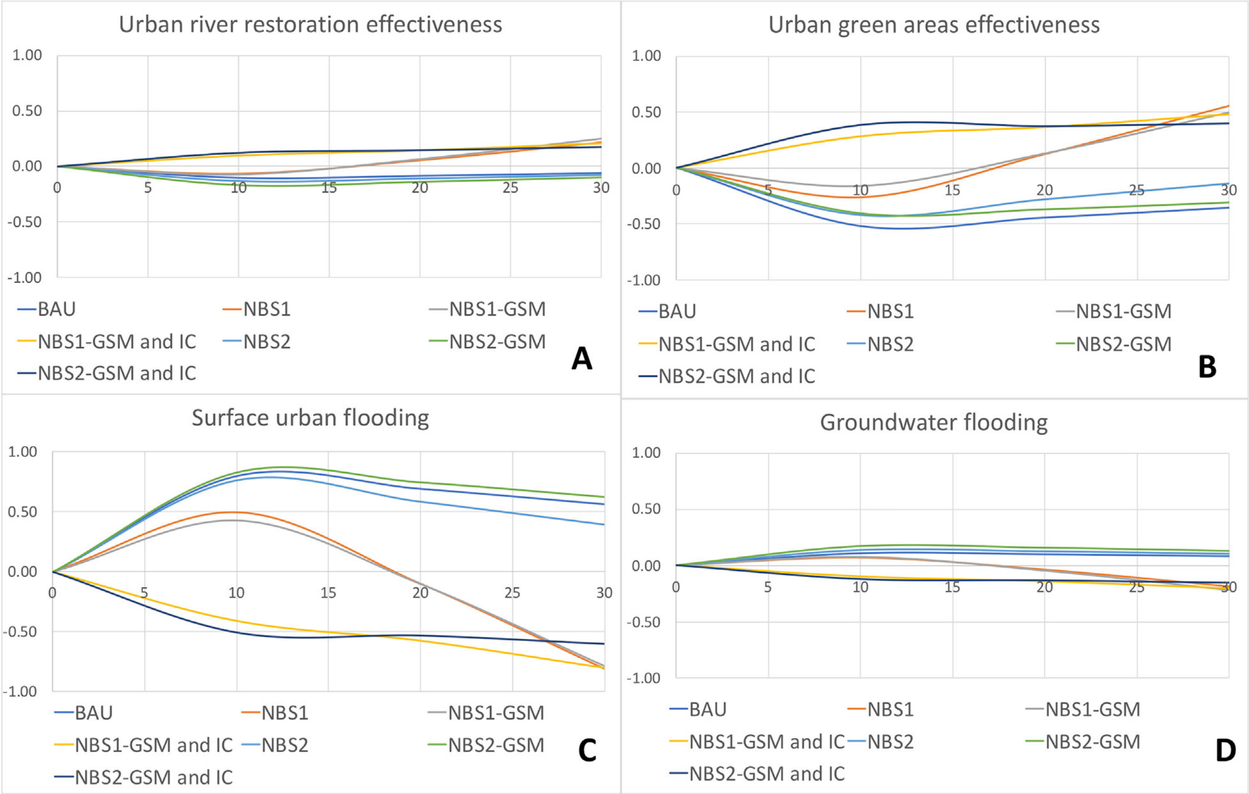

Fig. 4. Dynamic behaviour of NBS effectiveness (A-B) and surface and groundwater flooding (C-D). The x-axis represents time (in years) and the y-axis the value of the variables in each scenario.

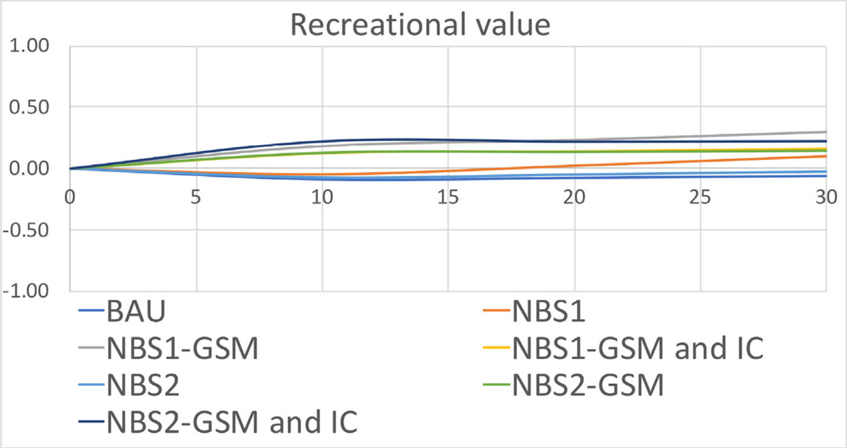

Fig. 5. Showing dynamic behaviour of co-benefits: Aesthetic value (A), Recreational value (B), Branding (C) and potential for economic opportunities and green jobs (D). The x-axis represents time (in years), and the y-axis the value of the FCM variables in each scenario. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

attractiveness of the city (branding co-benefit) has also a high impact on social justice. This occurs because these co-benefits help to increase property value. If the rise in prices is not controlled, a decrease in social-justice and cohesion follows. The increase of the real estate property value encourages urban development which, on the one hand increases Copenhagen wealth but on the other hand, decreases biodiversity. Firstly, scenarios NBS2-GSM-IC, NBS1-GSM-IC and NBS1-GSM encourage a higher delivery of aesthetic and recreational value co-benefits whereas biodiversity and social justice suffer a decrease in the same scenarios. As explained in Section 3.1, social justice is linked to other co-benefits (citizens awareness and citizens involvement and sense of ownership) through a series of self-reinforcing loops (R1, R2, R4 and R5). A decrease in social justice reinforces the decline of these other co-benefits. At the same time, this decrease negatively affects the social acceptance of NBS.

For more information of the results see Appendix D from supplementary material.

3.3. Sustainable development goals analysis

A list of SDGs that could be potentially influenced by NBS implementation for the case of Copenhagen is shown in this section. For a more complete list of these SDGs and their targets please see Appendix E.

We conclude that a minimum of 10 SDGs could potentially be affected by the implementation of NBS. The results reveal that the restoration of the urban river combined with an adjacent urban green area is more likely to produce a higher number of co-benefits in the long term and hence, a higher contribution to SDGs is expected (see Table 1). The results also expose that appropriate management regimes or measures designed to increase institutional collaboration increases

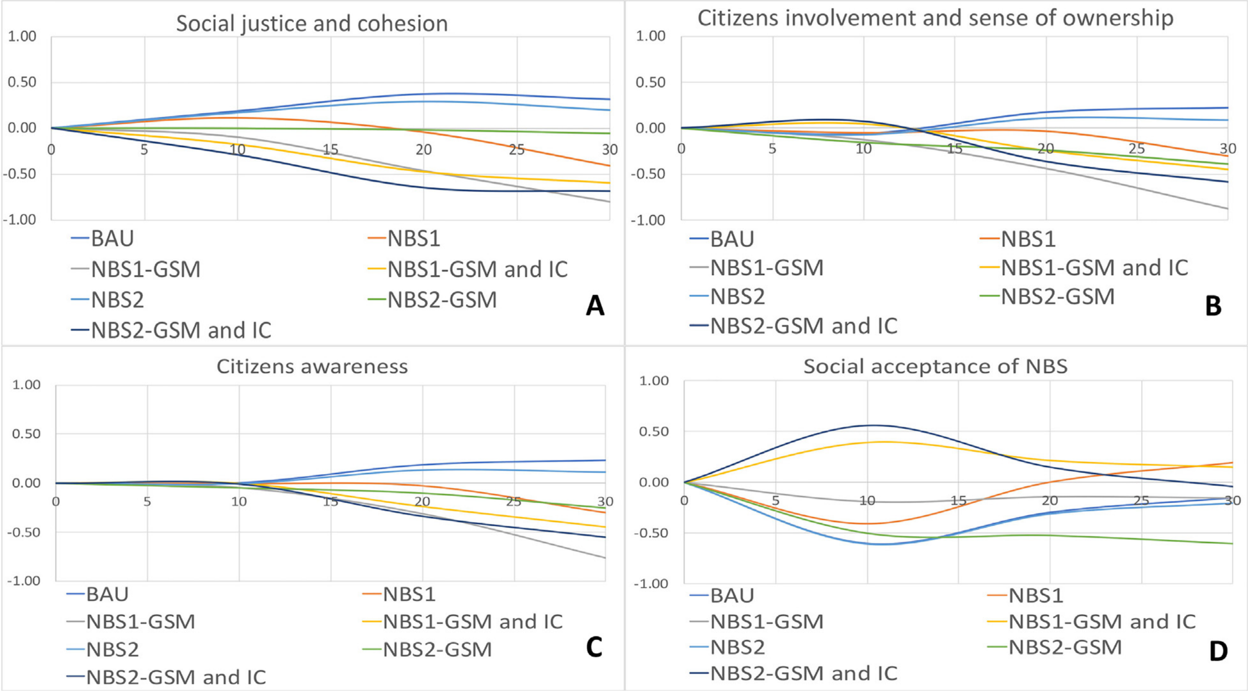

Fig. 6. Dynamic behaviour of co-benefits: Social justice and cohesion (A), citizens involvement and sense of ownership (B), citizens awareness (C) and social acceptance of NBS (D). The x-axis represents time (in years), and the y-axis the value of the FCM variables in each scenario.

Table 1
Sustainable development goals linked with NBS co-benefits.

Sustainable development goal linked to NBS co-benefits

Goals (from the 2030 Agenda)	Co-benefits	NBS1	NBS1-GSM	NBS1-GSM-IC	NBS2	NBS2-GSM	NBS2-GSM-IC
Goal 1. End poverty in all its forms everywhere	Potential for economic opportunities and green jobs	🟩	🟨	🟩	🟥	🟥	🟩
	Social justice and cohesion	🟨	🟥	🟨	🟥	🟥	🟥
Goal 3. Ensure healthy lives and promote well-being for all at all ages	Health and well being	🟨	🟨	🟨	🟥	🟥	🟨
	Water quality	🟨	🟨	🟨	🟥	🟥	🟨
Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	Social acceptance of NBS	🟨	🟥	🟨	🟥	🟥	🟥
	Social justice and cohesion	🟨	🟥	🟨	🟥	🟥	🟥
	Citizens awareness	🟥	🟥	🟥	🟨	🟥	🟥
Goal 6. Ensure availability and sustainable management of water and sanitation for all	Water quality	🟨	🟨	🟨	🟥	🟥	🟨
Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	Potential for economic opportunities and green jobs	🟩	🟨	🟩	🟥	🟥	🟩
Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	Potential for economic opportunities and green jobs	🟩	🟨	🟩	🟥	🟥	🟩
	Investment in green infrastructure	🟨	🟨	🟨	🟥	🟥	🟨
Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable	Surface urban flooding reduction	🟩	🟩	🟩	🟨	🟥	🟩
	Groundwater flooding reduction	🟩	🟩	🟩	🟥	🟥	🟨
Goal 13. Take urgent action to combat climate change and its impacts[b]	Urban heat island reduction	🟩	🟩	🟩	🟨	🟨	🟩
	Surface urban flooding reduction	🟩	🟩	🟩	🟨	🟥	🟩
	Groundwater flooding reduction	🟩	🟩	🟩	🟥	🟥	🟨
Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	Biodiversity	🟥	🟥	🟥	🟨	🟥	🟥
	Citizens awareness	🟥	🟥	🟥	🟨	🟥	🟥
Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	Social justice and cohesion	🟨	🟥	🟨	🟥	🟥	🟥
	Citizens involvement and sense of ownership	🟥	🟥	🟥	🟨	🟥	🟥

NBS effectiveness and boost the delivery of co-benefits. This implies that a higher influence on the SDGs is obtained. Trade-offs among co-benefits may limit the contribution of NBS to different SDGs. For example, SDGs 15, 16 and 4 will be weakly affected by NBS implementation due to the trade-off that exist between social justice and cohesion (and its related co-benefits) and those co-benefits that influence property value (i.e. aesthetic and recreational value, public health and well-being or city branding). In contrast, a higher contribution to SDGs 13, 11 and 8 is expected.

4. Discussion

In this paper, we assume that the capability of NBS for addressing SDGs may be enhanced by improving NBS multifunctionality and thus its effectiveness. NBS should be considered effective not only if they are capable of producing the expected co-benefits, but also if the production of co-benefits is balanced, which means, the capability of NBS to eliminate/reduce the level of trade-offs among different co-benefits. The long-term effectiveness of NBS depends not only on NBS design and implementation, but also on the socio-ecological context in which NBS are applied. For example, low level of institutional collaboration or lack of citizen awareness may hamper NBS effectiveness. External factors such as climate change may also influence NBS capability to deliver certain co-benefits over time. These issues need to be addressed prior to NBS design and implementation and requires a deep understanding of the complex relationships that exist among the social, economic and environmental factors of the considered system. We believe that trade-off identification in the prior stages of NBS implementation is crucial to enhance NBS multifunctionality and to pursue sustainable development. To this aim, system thinking modelling approach – i.e. Fuzzy Cognitive Mapping (FCM) – was adopted to explore the structural causes of the observed trends as well as to analyse and map the complex network of interactions among the components involved in NBS effectiveness. In this paper we have demonstrated that FCM combined with a participatory modelling phase is an appropriate methodology to handle the diversity in framing NBS complexity among the different stakeholders. FCM has provided different advantages in the process of analysing the river restoration NBS multifunctionality. It has allowed us to capture the essence of the whole system comprehensively, without making the model too complex to be used with the stakeholders. Compared to other methods for dynamic analysis, FCM demonstrated great potential in facilitating the interaction with stakeholders. FCM did not force the analysts to translate stakeholders' knowledge and narratives – which are mainly qualitative – into quantitative variables and equations, as already discussed in (Kok, 2009; Jetter and Kok, 2014). The FCM model for scenario simulation was built referring to the stakeholders' knowledge elicited during the early phases of anticipated project implementation. Therefore, participants were familiar with the causal connections described in the model and were able to understand the model. We learned that the adoption of a qualitative modelling approach, such as the FCM, positively affected the interaction with the stakeholders for both the model building phase and the scenario development.

This work is in line with the efforts already carried out aiming at developing integrated frameworks for assessing NBS effectiveness accounting for the production of co-benefits (see Raymond et al., 2017; Alves et al. (2019a, 2019b); Pagano et al., 2019). Compared to the above cited works, the approach described in this article introduced several novelties. Contrary to the works of (Pagano et al., 2019; Giordano et al., 2020), the activities carried out in the Copenhagen case study demonstrates the suitability of a group model building approach for developing the FCM model as the basis for the co-benefits and trade-off analysis. This approach has multiple elements of relevance. Firstly, it allows actors/stakeholders to share their knowledge/expertise. Secondly, it facilitates the creation of social capital among participants by providing a means for group identification of common problems and solutions, as well as the optimal way to test them. Finally, the group discussion reduced the biases introduced by the analyst during the aggregation phase. Nevertheless, trade-offs among co-benefits may arise due to differences among stakeholders' perceptions which means that co-benefits delivered by NBS may be valued differently depending on the stakeholder. Considering this, the adopted approach presents limitations concerning the lack of analysis of the differences between diverse kinds of stakeholders. Therefore, the analysis carried out accounted solely for the trade-offs among co-benefits, and not those between stakeholder's valuation.

The work also demonstrates the need to account for the time dimension in detecting and assessing trade-offs among different co-benefits. Importantly, the results of the FCM-based scenarios show that the same NBS can produce different co-benefits at different time steps. Thus, potential trade-offs might not appear because of the time delay. Conversely, the delays in co-benefits production could negatively affect the synergies between different co-benefits and NBS. For example, the results show that the implementation of NBS in Copenhagen (i.e. urban river restoration) is highly likely to produce a rapid increase of some co-benefits such as recreational and aesthetic value or city branding. However, the results also show that in the long term, the increase of these co-benefits may hamper the delivery of other co-benefits such as social justice and cohesion, social acceptance of NBS or citizens awareness. This is because urban green spaces usually correlate with an increase of properties and rent prices. This may displace groups of people that cannot afford the increase in real estate prices, consequently decreasing social justice and the social acceptability of NBS.

As highlighted by several authors, NBS have proven to be a cost-effective solution that can simultaneously contribute to several societal challenges. In the case of Copenhagen, the restoration of the urban river combined with an integrated urban green area is perceived by the stakeholders as an effective solution capable of delivering sets of benefits that contribute to a range of SDGs (i.e. SDG 5, 6, 4, 13, 11). The benefits delivered by NBS not only vary across spatial and temporal scales but also among societal groups. For this reason, new methods and approaches are needed to account for the real contribution of NBS to SDGs.

5. Conclusion

Assessing the dynamic behaviour of trade-offs and synergies among co-benefits could help to anticipate, identify and solve resistance to adopt policies and suitable strategies to implement NBS. The method proposed in this article has provided different advantages in the process of analysing the river restoration multifunctionality, and its capability to produce benefits over time. Firstly, it has supported the integration of quantitative and qualitative variables, knowledge and issues that are not well-defined or uncertain. Secondly, it has helped to show the complex interconnections and feedback processes within the system helping to infer intended and unintended consequences of NBS implementations. Lastly, besides the model, the whole process itself has promoted awareness and motivation of those taking part in decision- or policy-making processes, thus providing a platform for the joint-ownership of results. Despite all these advantages, new participative modelling tools focusing not only on a subset of impacts but on an integrated view of the system are needed to show the advantages of NBS over other adaptation strategies. Only this way could NBS be meaningfully and effectively integrated in national and international development policies.

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CRediT authorship contribution statement

Eulalia Gómez Martín: Conceptualization, Methodology, Writing - original draft.**Raffaele Giordano:**Conceptualization, Methodology, Writing - review & editing.**Alessandro Pagano:**Conceptualization, Methodology, Writing - review & editing.**Peter van der Keur:**Conceptualization, Writing - review & editing.**María Máñez Costa:**Conceptualization, Writing - review & editing.

Declaration of competing interest

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

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