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Enhancing nature-based solutions acceptance through stakeholders' engagement in co-benefits identification and trade-offs analysis

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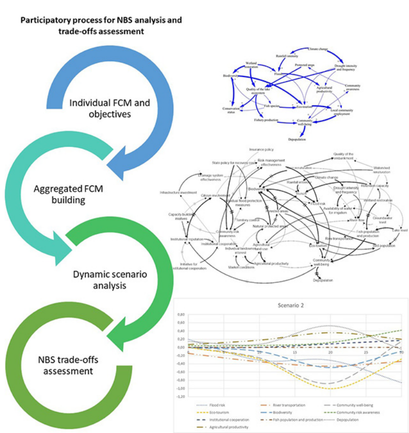
HIGHLIGHTS

- Evidences regarding the NBS effectiveness in producing co-benefits are required in order to facilitate their implementation.
- Engaging stakeholders in developing frameworks for assessing NBS effectiveness is key.
- Differences in co-benefits perception and valuation might lead to trade-offs among stakeholders.
- Including the time dimension in the trade-offs analysis allows to define when a potential conflict could emerge.

GRAPHICAL ABSTRACT



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ABSTRACT

Nature-based solutions (NBS) are increasingly recognized as a valid alternative to grey infrastructures - i.e. hard, human-engineered structures – as measures for reducing climate-related risks. Increasing evidences demonstrated that NBS can reduce risks to people and property as effectively as traditional grey infrastructures, but potentially offering many additional benefits, e.g. improving the natural habitat for wildlife, enhancing water and air quality, improving socio-cultural conditions of communities. The growing attention on the NBS, triggered an increasing interest in developing integrated and multi-disciplinary frameworks for assessing NBS effectiveness accounting for the co-benefits production. Starting from the analysis of the existing frameworks, this work claims for a more direct engagement of stakeholders – i.e. co-benefits beneficiaries – in developing NBS assessment framework. This work aims at demonstrating that differences in co-benefits perception and valuation might lead to trade-offs and, thus, to potential conflicts. An innovative methodology using a quasi-dynamic Fuzzy Cognitive Map approach based on multiple-time-steps was developed in order to assess NBS effectiveness, and to detect and analyze trade-offs among stakeholders due to differences in co-benefits perception. The developed methodology was implemented in the Lower Danube case study. The trade-off analysis among stakeholders shows that they are quite low in the short term. Most of the potential conflicts can be detected in the long term, involving mainly the stakeholders that assigned a high value to the agricultural productivity variable.

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The results demonstrated that accounting for the different stakeholders' perception of the co-benefits is key for reducing trade-offs and enhance NBS acceptability.

1. Introduction

In recent years, disasters triggered by natural hazards – and specifically those related to climate change and climate variability, such as flood, drought and heat waves - have demonstrated the need for effective risk management measures to minimize their impacts on the build environment, communities and the economy, e.g. human casualties and damages to the building and economic activities. Over 2010–2016, the economic losses caused by extreme weather and climate in the 33 European countries amounted to approximately €12.8 billion a year (EEA, 2018). The Global Facility for Disaster Reduction and Recovery estimates that in the last 30 years, $3.8 trillion was lost worldwide to disasters triggered by natural hazards (GFDRR, 2013). In 2017 alone, natural hazards caused overall losses of US$ 340b, which was the second-highest annual loss ever and almost double the previous year's level (Jeworrek, 2018).

Nature-based solutions (NBS) have become a valid alternative to grey infrastructures – i.e. hard, human-engineered structures (Palmer et al., 2015) – for coping with climate-related risks in urban and rural areas alike (Raymond et al., 2017; Calliari et al., 2019; Frantzeskaki, 2019; Sepehri and Sarrafzadeh, 2019). NBS are defined by the European Commission as solutions for addressing societal challenges (such as risk management) that are "inspired by, supported by or copied from nature" and "simultaneously provide environmental, social and economic benefits and help build resilience" (European Commission, 2015). In this work, NBS were considered solutions for addressing water-related risks. NBS are increasingly recognized for their capacity to foster the functioning of ecosystems and to generate additional environmental, economic and social benefits that are considered as essential backbones of actions for climate-change mitigation and adaptation (Bain et al., 2016; Kabisch et al., 2016; Josephs and Humphries, 2018). Nevertheless, the transition of the risk management system from the grey solutions toward NBS is still slow (Wihlborg et al., 2019). In order to be preferred over conventional grey and hybrid interventions, comprehensive assessments are needed to prove NBS effectiveness in dealing with climate-related risks while capturing the diverse benefits (Calliari et al., 2019). The growing attention in NBS by policy- and decision-makers triggered an increasing interest in research of mapping and collecting evidence of their multiple benefits (Frantzeskaki, 2019; Raymond et al., 2017; Alves et al., 2019a). Indeed, several societal challenges that can be tackled through the production of NBS co-benefits – i.e. social, economic and environmental benefits produced through the implementation of NBS (Raymond et al., 2017) – have been identified in the EKLIPSE framework (Raymond et al., 2017), namely 1) Climate mitigation and adaptation; 2) Water management; 3) Coastal resilience; 4) Green space management (including enhancing/conserving urban biodiversity); 5) Air/ambient quality; 6) Urban regeneration; 7) Participatory planning and governance; 8) Social justice and social cohesion; 9) Public health and well-being; 10) Potential for new economic opportunities and green jobs.

Most of the scientific efforts for demonstrating the NBS effectiveness and for improving the measurability of the produced co-benefits, focuses on the development of integrated sets of indicators, e.g. distribution of public spaces, recreation or cultural value, openness of participatory process, etc. (e.g. Calliari et al., 2019; Kabisch et al., 2016; Raymond et al., 2017). For instance, Kabisch et al., 2016 and Xing et al., 2017 examined indicators of NBS effectiveness at the urban scale, although with a level of abstraction that does not support a comparison with different alternatives. A guidance on NBS for flood risk management, as alternative or complementary to conventional engineering measures, was proposed by the World Bank (2017).

Although the mentioned approaches have been implemented in monitoring and assessing NBS effectiveness, they have some limitations. Firstly, they have a limited capability to fully analyze the NBS potential for producing co-benefits (e.g. Kabisch et al., 2016), being limited to the analysis of a subset of impacts (mainly environmental) and rarely addressing the cross-sectoral ones. In particular, there are some aspects such as the socio-cultural, economic and ecosystem interactions, that require further consideration. Secondly, it should be considered that they are generally static, i.e. the analysis of NBS is performed assuming that both the NBS and the conditions in which they are set to operate (e.g. climate, urbanization, etc.) are immutable and not affected by any change (Calliari et al., 2019). Lastly, most of the existing frameworks are limited in terms of stakeholders' involvement, and, consequently do not support the management of the unequal distribution of the co-benefits' fruition among the different potential beneficiaries.

Specifically, stakeholders might differently perceive and evaluate the co-benefits. NBS and the associated co-benefits have many potential uses with different values attached, that can be perceived differently from different beneficiaries. The differences among the stakeholders concern the kinds of benefits to be valued, and the values to be attached, which are strongly affected by the individuals' benefits perception (Sanon et al., 2012; Jacobs et al., 2016; Small et al., 2017). Neglecting these differences and ignoring the consequences of trade-offs between values held by different stakeholders, which in many cases are not well represented in the decision-making process, may lead to conflict, and thus to policy resistance mechanisms (Giordano et al., 2017; Howe et al., 2014; Jacobs et al., 2016; Small et al., 2017; Wam et al., 2016; Shrestha and Dhakal, 2019).

This work describes an innovative methodology for assessing NBS effectiveness, and for detecting and analyzing trade-offs between beneficiaries. It aims to discuss to what extent the described methodology is capable to: (i) detect and analyze differences in stakeholders' values and perceptions of the multi-dimensional benefits; (ii) raise awareness of what situations may produce a trade-off with an understanding of why (and what) trade-offs could result from NBS implementation; and (iii) resolve potential conflicts over NBS implementation and co-benefits evaluation. In other words, this paper aim to demonstrate that accounting for the differences in stakeholders' perception of NBS co-benefits and values is the key for enhancing the NBS social acceptance and, thus, facilitate their implementation.

Within this context, a methodology based on Fuzzy Cognitive Maps (FCMs) was developed and implemented. A FCM is a systems mapping method applied to several disciplines dealing with complex decision environments. FCM captures expert knowledge, allowing to identify complex interrelations among elements affecting the dynamic evolution of the system (Olazabal et al., 2018). It is a method that allows the integration of multiple expert perspectives (Olazabal and Pascual, 2016), and it allows scenario development (e.g. Pluchinotta et al., 2019), that is, building "what if" stories about the future, expressed through the values of the FCM variables (Kok, 2009). In this work, FCMs were implemented as a Problem Structuring Method (PSM) for eliciting stakeholders' values and perceptions about NBS effectiveness and co-benefits production. The FCM were then used for analyzing potential trade-offs accounting for the dynamic evolution of the system affected by the NBS implementation. The described methodology was developed within the framework of the EU funded project NAIAD and implemented in the lower part of the Danube river basin.

The manuscript is organized as following. Section 2 describes the different steps of the methodology. Section 3 discusses the results obtained in the Lower Danube case study, while Section 4 is meant to share the main lessons learned from the implementation of the developed methodology.

2. Materials and methods

Fig. 1 shows the different phases of the implemented methodology.

The common ground for the different phases is the active participation of different categories of stakeholders in the process, ranging from institutional actors responsible for the design and implementation of NBS and other actions for managing water-related risk, to the members of local communities that could benefit from the NBS implementation. Different methods for supporting the stakeholders' participation were implemented in the different phases of the methodology, as described in the following sections. The selection of the participants was carried out trying to minimize the selection bias and the marginalization of stakeholders (Ananda and Herath, 2003; Reed et al., 2009)

In order to minimize top-down stakeholder identification practice, a systematic sampling method which is referred as “snowballing” or “referral sampling”, was implemented (Reed et al., 2009). The selection process started with the actors mentioned in the official protocols, i.e. the decision actors whose main responsibility is to develop strategies and plan for risk management. The preliminary interviews carried out with these agents allowed to widen the set of stakeholders to be involved (Giordano et al., 2017). Secondly, the main stakeholders' concerns and needs related to risk management were accounted for in order to guarantee the long-term involvement of the selected stakeholders.

2.1. Individual problem understanding and objectives elicitation

Problem Structuring Method (PSM) approach was implemented in order to support decision-makers and stakeholders in structuring their own risk and co-benefits perceptions, PSM was selected because it allowed to account for the differences between stakeholders' perceptions and contributed to detect main trade-offs between stakeholders due to the implementation of the NBS.

Among the different PSM (see e.g. Mingers and Rosenhead, 2004), a Fuzzy Cognitive Map (FCM) based approach was implemented. FCM is frequently used in order to capture the values in a group of individuals and to reduce the antagonism between such values (Eden and Ackermann, 2004). A FCM is composed by interrelated variables and directional edges, i.e. connections – representing the causal relationships between variables (Kok, 2009). The connections are defined by a fuzzy weight which describes the strength of the causal relationship between two variables (Kosko, 1986). The connection strength indicates the stakeholder's perceived influence of two variables on each other (Özesmi and Özesmi, 2004). The weights of the arcs are usually in the interval [−1,1] (Papageorgiou and Kontogianni, 2012). A positive weight indicates an excitatory relation between two connected variables – i.e. the increase of one variable leads to the increase of the connected one – while a negative weight indicates an inhibitory connection – i.e. the increase of one variable leads to the decrease of the other. The weights of the arcs represent the strength of the causal connection between two variables.

Considering that this work mainly aimed at enhancing the potential richness, diversity and complexity of the collected knowledge, rather than searching consensus among participants, individual FCM were developed referring to the results of semi-structured interviews with local stakeholders (Olazabal et al., 2018). The semi-structured interviews were designed according to the mean-end approach. Specifically, the interviews aimed at gathering stakeholders' understandings about: (i) the main elements affecting the water-related risks at local level; (ii) the direct and indirect expected impacts; and (iii) the most important issues (social challenges) that need to be addressed in order to increase the effectiveness of the risk management actions and enhance the system conditions (Bain et al., 2016). Finally, stakeholders were required to specify the expected roles of the NBS in reducing water-related risks and addressing the social challenges.

The interviews were, then, analyzed in order to detect the keywords in the stakeholders' argumentation – i.e. the concepts in the FCM – and the causal connections among them – i.e. the links in the FCM. In order to reduce the biases potentially introduced in the process by the analyst during this phase, a structured approach was implemented (Jetter and Kok, 2014; Olazabal et al., 2018). Participants were provided with instructions to understand FCM semantics (i.e. concepts and links) together with some examples. Moreover, in order to facilitate the development of the individual FCM, the interviews were designed in such a way as to make the cause-effect relations immediately identifiable in the stakeholders' argumentation. The collected knowledge was, hence, processed in order to obtain the individual FCM. Specifically, structural relationships forming the FCM topology were defined accounting for the causal assertions made by individuals. The sentences were broken down into specific categories, i.e. (i) cause variables; (ii) effect variables; and (iii) relationships type (Kim and Andersen, 2012). Table 1 shows an example of the stakeholders' argumentation analysis, allowing to detect the structural relationships for FCM development.

Once developed, the individual FCM were analyzed in order to infer stakeholders' objectives. Two sequential analyses were carried out. Firstly, the centrality degree measure was assessed to detect the most

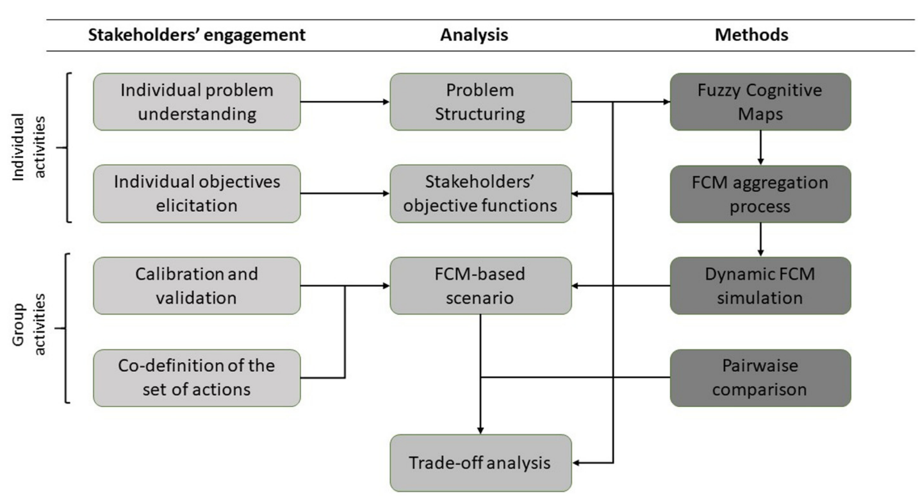

Fig. 1. Different phases of the implemented methodological approach.

Table 1
Examples of the analysis of the interviews for developing the structural relationships in the FCM.

Quotes from the interviews	Cause variables	Effect variables	Relationship type
"Poor maintenance increases the flood risk due to the canal's effectiveness"	Canal maintenance	Canal effectiveness Flood risk	Positive Negative
"The urban elements affecting the intensity of flood risk are mainly the lack of urban planning and citizens' behaviour, producing unregulated settlements"	Urban planning Citizens' behavior	Unregulated settlements Flood risk	Positive Negative

important elements in the stakeholders' perception, the so called "nub of the issue" (Eden, 2004). The more central the variables, the more important the concept is in the stakeholder's perception. The centrality degree of each concept was calculated analyzing the complexity of the surrounding causal chains (Ackermann and Alexander, 2016; Ackermann et al., 2014; Santoro et al., 2019). Section 1.1 in the Supplementary material describes the procedure for assessing the centrality degree for the stakeholders' FCM.

Secondly, FCM scenario analysis (Kok, 2009) was implemented in order to define the expected NBS impacts according to the stakeholders' problem understanding. Section 1.2 in the Supplementary material describes how stakeholders' FCM can be used for scenario analysis. The NBS impacts on the variables in the FCM were defined referring to the following formula (Kosko, 1986; Kok, 2009):

$$x_i(t) = f(\sum_{j=1}^{n} x_j(t-1)w_{ij} \quad (1)$$

That is, the value of the variable x_i at interaction step t depends on the value of the connected variable x_j at the interaction step $(t-1)$ and the weight of the connection between these two variables. *f* represents a threshold function whose main scope is to normalize the values of the FCM variable at each step to keep the dynamic analysis bounded. Usually, the variables values are bounded in the interval $[-1,1]$ (Gray et al., 2015). FCM outputs are semi-quantitative and do not have physical meaning. The FCM outputs in one scenario can be only interpreted relative to the outputs in another scenario (Kok, 2009). In this work, the comparison between the value of the variables in case of NBS implementation and without NBS allowed us to assess the stakeholders' expected impacts, i.e. impact degree in this methodology. Fig. 2 shows the comparison between the FCM variables in case of NBS implementation and without NBS. A FCM developed in the Lower Danube case study was used to this aim. Please, refer to the Section 1.2 in the Supplementary materials for more details on the FCM scenarios calculation.

The impact degree was, then, assessed as degree of change in the FCM variables (see Section 1.2 of the Supplementary material).

The aggregation between the centrality degree and the impact degree allowed to define the importance degree and, then, to rank the variables in the individual's FCM and to identify the stakeholders' objectives. The proposed approach assumes that a stakeholder attributes a high importance to a certain variable in the FCM if it is central in the FCM and if the NBS is expected to provoke a significant change in its state. Fuzzy linguistic functions were defined for describing the centrality, impact and importance degree (Fig. 3).

In these graphs, the *x-axis* describes the numerical base of the variables centrality, impact and importance degree. The *y-axis* represent the membership degree of the crisp values to the three fuzzy sets "Low", "Medium" and "High" (Zimmermann, 1991). For a more detailed description of how to elicit fuzzy functions from stakeholders, a reader might refer to Page et al. (2012). Fuzzy *if…then* rules and fuzzy inference were implemented in order to aggregate the centrality degree and the impact degree and to calculate the importance degree for the FCM variables (see Section 1.3 in the Supplementary material for further details). The variables with the highest importance degree were selected as the key stakeholders' objectives. A weight was assigned to

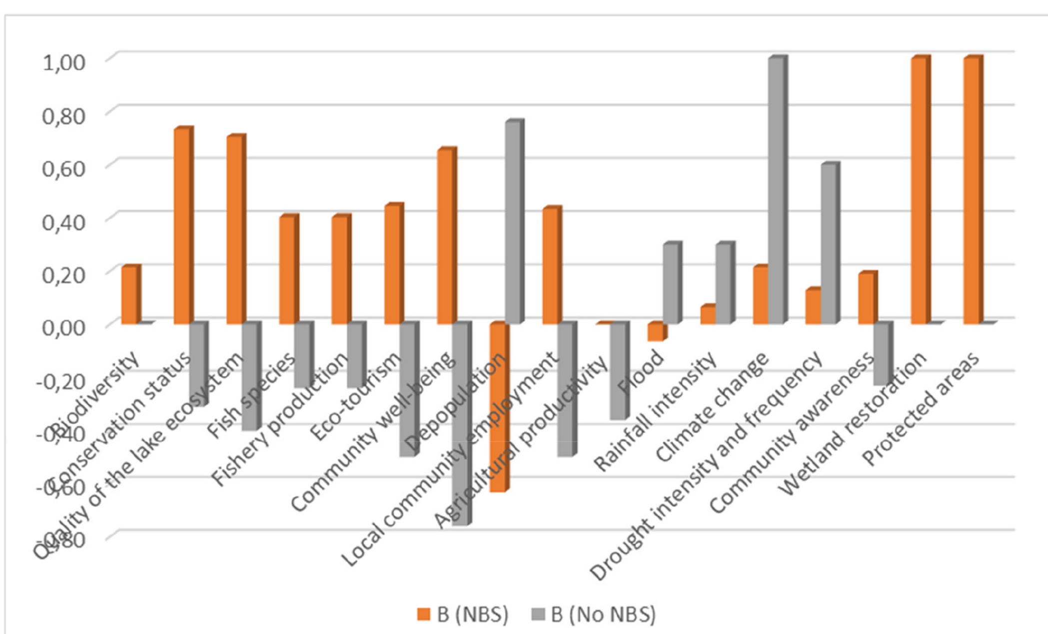

Fig. 2. Simulated change of the FCM variables due to the NBS implementation.

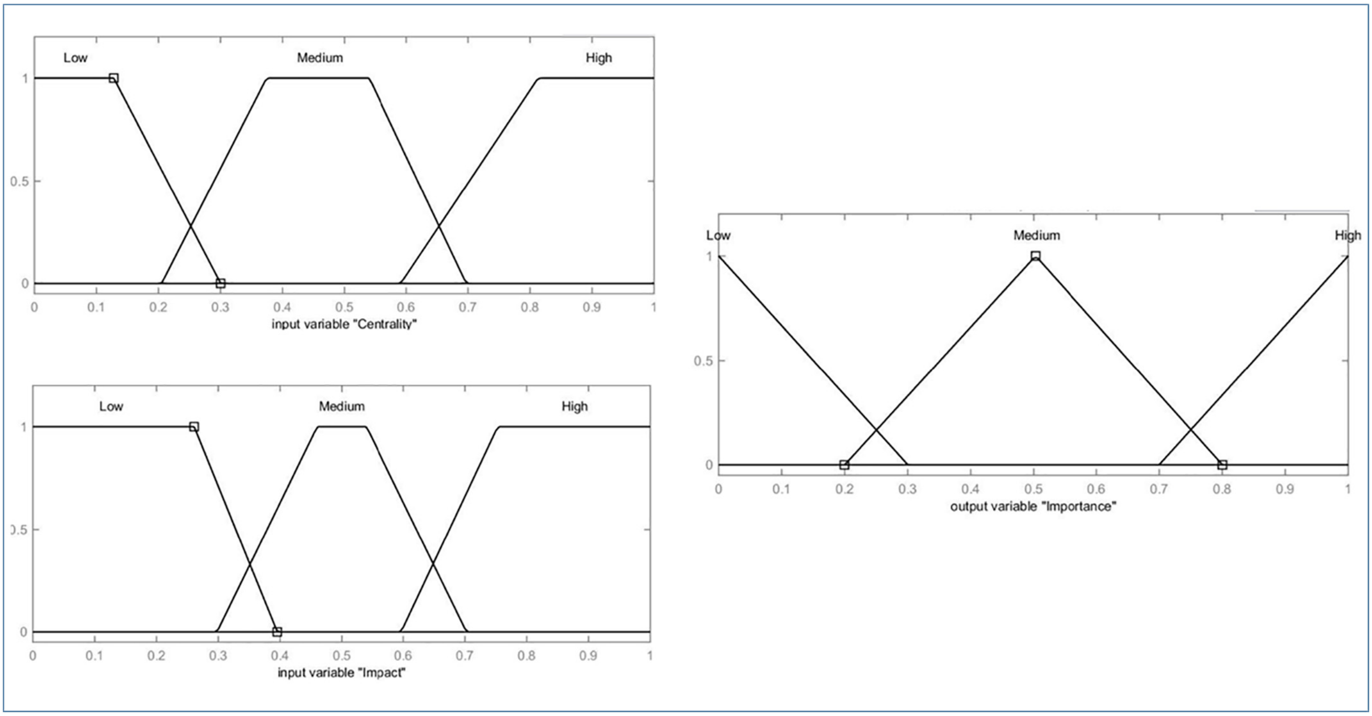

Fig. 3. Fuzzy linguistic functions describing the centrality, impact and importance degree for the FCM.

the different objectives according to the importance degree. Eq. (2) was implemented for defining the stakeholders' objective function.

$$F(O)_i = \sum_{j=1}^{n} O_{ij} * W_{ij} \tag{2}$$

Specifically, $F(O)_i$ represents the objective function for the i-th stakeholder; O_{ij} is the value assumed by j-th objective due to the NBS implementation, and W_{ij} represents the weight of the j-th objective in the i-th stakeholder's FCM. $\sum W_{ij} = 1$.

The individual functions were, then, used to detect and analyze potential trade-offs among different stakeholders due to the NBS implementation, as discussed further in the text.

2.2. FCM aggregation process and scenario simulation

This phase of the developed methodology was meant to assess the NBS effectiveness by simulating the impacts on the system due to the NBS implementation. At this stage, we shifted the focus from individual's problem perception to the system understanding and dynamic evolution. As described in Section 2.1 of the Supplementary material, the mathematical aggregation procedure suggested by Kosko (1986) was implemented for developing the aggregated FCM.

The FCM capability to facilitate the creation of scenarios that bridge the gap between quantitative analysis and qualitative story lines was used (Jetter and Kok, 2014). In this work, scenario was defined as a "what-if" story about the future conditions of the studied system, told through the values of the FCM variables, offering an internally consistent and plausible explanation of how events unfold over time (Kok, 2009). Alternative scenarios were developed, reflecting the knowledge of the involved stakeholders, and shaped by different combinations of input variables (Jetter and Kok, 2014).

Prior to use the aggregated FCM for simulating the dynamic of a system due to the implementation of NBS, some methodological issues need to be addressed. The most important one concerns the inclusion of time and delays in the FCM scenario simulation. As pointed out by Kabisch et al. (2016), one of the key knowledge gaps in assessing NBS effectiveness is related to the time scale of NBS implementation and co-benefits production. NBS require time for being effective, and different co-benefits can be produced at different time steps. Some of the expected co-benefits can be produced in the immediate aftermath of the NBS implementation or even during the process of NBS design, whereas others can emerge in the long terms – e.g. ecosystem restoration and biodiversity increase. Therefore, in order to be used in this work for detecting and analyzing trade-offs due to co-benefits production, FCM should be capable to simulate the dynamic evolution of the system variables accounting for different time lags and delays. This represents a limit of the traditional approaches for FCM development, as pointed out by several authors (e.g. Jetter and Kok, 2014; Kok, 2009). Traditional FCM allows only a semi-quantitative analysis of the temporal dynamics. The output of FCM shows the values of the variables after a number of iterations, which cannot be directly translated into time steps, unless the FCM is characterized by processes that are assumed to act at the same time scale. This means that traditional FCM does not allow considering delays in the connections among different variables. Moreover, the number of iterations it takes for the system to settle down cannot be interpreted as the time it takes the real-world system represented by the FCM to reach a quasi-stable state (Jetter and Kok, 2014).

In order to overcome the above mentioned drawbacks, this work assumes that delays can be introduced in the FCM by allowing changes in the adjacency matrix. In traditional FCM, the adjacency matrixes are supposed to be constant. The edges connecting variables are characterized by two elements, i.e. the polarity and the weight, that are assumed to be invariable over time. In this work, we assumed that both the polarity and the weight can change over time, accounting for the expected dynamic of the causal connections in the real world. Specifically, three different adjacency matrixes were developed at three different time steps, i.e. short term, medium term and long term. The weights to be assigned to the causal connections in the three time-steps were elicited by interacting with key local stakeholders. A sequential implementation of the FCM calculation (Eq. (1)) was carried out using the three different adjacency matrices, as described in Section 2.2 of the Supplementary materials. The dynamic evolution of the FCM variables was obtained by plotting the variables' state in the three time steps.

2.3. FCM validation and trade-off analysis through pairwise comparison

Prior to use the aggregated FCM for developing risk management scenarios, a validation phase was needed. The validation of the aggregated FCM was carried out accounting for the qualitative nature of the model. It is worth mentioning once again that FCM were not meant to simulate the actual behavior of the real system. FCM were rather implemented in this work because of their capability to create a useful and formalized description of the perception of a group of experts and stakeholders of the problem under consideration (Jetter and Kok, 2014). Therefore, contrarily to most of the quantitative models used in environmental science, a FCM should be considered validated if it adequately describes the participants' understanding about the subject matter. In this work, the calibration was carried out by describing to the stakeholders the complex causal networks affecting the behavior of the key variables in the FCM, accounting for both direct and indirect effects, and by discussing the system behavior in simple cases for the key variables. Group discussion with a limited number of stakeholders – that is, the most experienced ones - and leaded by the analysts, was organized to this aim. The results of the discussion were used for improved the FCM capability to describe the participants' understanding of the system dynamic.

The validated FCM was used for assessing the impacts of the NBS implementation on the system dynamic. To this aim, a stakeholder-based scenario development workshop was organized. Stakeholders were required to define sets of actions to be implemented in order to reduce the water-related risk. The sets of actions had to be based on the integration between NBS and soft measures – i.e. actions aiming at enabling changes in the socio-institutional system in order to facilitate the implementation of NBS (e.g. "capacity building initiatives", "institutional cooperation", "risk awareness campaigns", etc.). In order to facilitate the stakeholders' participation, a catalogue of suitable NBS and a list of soft measures were provided at the beginning of the workshop. The results of the individual interviews were used to this aim. Participants were required to develop different combinations of NBS and soft actions. The developed sets of actions were, then, used for simulating alternatives NBS scenarios using the aggregated FCM. The stakeholders were, hence, required to select the most suitable scenario.

Finally, a trade-off analysis was carried out. We assumed that there was a trade-off between two stakeholders if there was an unequal distribution of the co-benefits. A stakeholder would not capture a NBS co-benefit – or would have a limited access to the co-benefits – if the value of her/his objective function due to the NBS implementation would be lower than expected. This is because the stakeholders' objective functions were defined in this work accounting for their perception of – and preferences over – the NBS co-benefits.

The desirable values of the objective functions were defined referring to the stakeholders' perception about the optimal evolution of the variable related to the co-benefits. Specifically, stakeholders were asked individually to draw the desirable shapes for the variables connected to the co-benefits. In order to facilitate the stakeholders in carrying out this task, supporting material was prepared referring to the most typical modes of system behavior, as explained by Vennix et al. (1996). The meaning of the fundamental modes (exponential growth, goal-seeking and oscillation), of the non-linear interactions of the fundamental modes (S-shaped growth, Growth with overshoot, Overshoot and collapse), and of the equilibrium and randomness were simplified and described to the stakeholders. Starting from these exemplary functions, the stakeholders were asked to describe the desirable evolution of the co-benefits variables.

Fig. 4 shows the comparison between the desirable scenario and the NBS scenario for two hypothetical stakeholders, X and Y. For sake of simplicity, we assume that A and B expressed interest in the same co-benefit. Nevertheless, they had a quite different perception of the desirable trend for the associated variable.

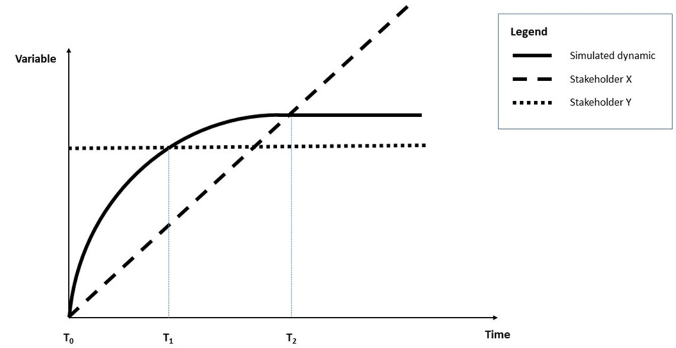

Fig. 4. Comparison between the desirable dynamic evolution and simulated value for the hypothetical co-benefit C according to the perception of two hypothetical stakeholders X and Y.

The variable associated to the selected co-benefit had a "goal seeking" behavior in the FCM simulation. Stakeholder X had a "linear" perception of the evolution, whereas stakeholder Y perceived the co-benefit as constant in time. The two stakeholders will benefit from the NBS implementation in different time steps. On the one hand, stakeholder X will perceive a benefit until time T_2, because the desirable value is lower than the one obtained by implementing the NBS. After this time step, she/he will perceive a dis-benefit. On the other hand, stakeholder Y will have a quite negative perception of the NBS co-benefit in the early stage of the implementation. After time T_1 she/he will gain a benefit.

This example shows the importance of adopting a dynamic approach in the analysis of the trade-offs among stakeholders. To this aim, a two-steps methodology was implemented. In the first step, the comparison among the objective functions in the desirable scenario and the NBS-based scenario was carried out for each stakeholder. The Table 2 shows the results of this step.

If the difference $F(Os)_i^1 - F(Od)_i^1$ is positive, then the i-th stakeholder will perceive a benefit due to the implementation of the NBS. Otherwise, a dis-benefit will be perceived.

In the second step, a pairwise comparison among the perceived benefits by each stakeholder will be carried out at each time step. Assuming that n stakeholders were involved in the exercise, the following matrix was developed for the j-th time step.

Table 3 shows the distance among the perceived benefits for the involved stakeholders, which was considered in this work as a measure of the trade-off between pairs of stakeholders. This analysis allowed to detect potential conflicts due to the NBS implementation, and to define the time steps when these conflicts might emerge. The basic assumption is that the higher is distance and the more likely is the conflict due to the trade-off.

3. Results

3.1. Case study description: flood and drought protection in the Lower Danube

The described methodology was implemented to assess the effectiveness of the NBS implementation project for reducing flood and

Table 2
Assessment of the perceived benefit for the i-th stakeholder.

Time	Desirable scenario	NBS scenario	Perceived benefit
1	$F(Od)_i^1$	$F(Os)_i^1$	$D_i^1 = F(Os)_i^1 - F(Od)_i^1$
2	$F(Od)_i^2$	$F(Os)_i^2$	$D_i^2 = F(Os)_i^2 - F(Od)_i^2$
3	$F(Od)_i^3$	$F(Os)_i^3$	$D_i^3 = F(Os)_i^1 - F(Od)_i^1$
…	…	…	…
n	$F(Od)_i^n$	$F(Os)_i^n$	$D_i^n = F(Os)_i^1 - F(Od)_i^1$

Table 3
Pairwise comparison among the benefits perceived by the different stakeholders at time j.

	S_1	S_2	…	S_n
S_1	–	$\lvert D_1^j - D_2^j \rvert$	…	$\lvert D_1^j - D_n^j \rvert$
S_2	$\lvert D_2^j - D_1^j \rvert$	–	…	$\lvert D_2^j - D_n^j \rvert$
…	…	…	…	…
S_n	$\lvert D_n^j - D_1^j \rvert$	$\lvert D_n^j - D_2^j \rvert$	…	–

drought risk in the lower part of the Danube river basin. Fig. 5 shows the study area.

The Lower Danube case study has a twofold objective, both associated to the climate extremes occurring in the upstream Romanian part of the river. On the one hand, to support flood risk reduction by reconnecting floodplains to wetlands; on the other hand, to tackle the issue of seasonal and inter-annual low-flows due to the occurrence of drought events.

Specifically, the first issue stems from a recent series of floods (2005 and 2006) along the Lower Danube. Climate change is considered a driver for the increase of risk level, as well as the intensification of urbanization and anthropic pressures (e.g. a large part of the Danube floodplains have been lost in the past century due to the construction of dykes). Several initiatives to limit flood risk have been promoted and are still being implemented, such as the Lower Danube Green Corridor, which aims to reconnect the natural flooding areas through structural interventions (e.g. lowering dykes) and renaturation processes (e.g. re-meandering and reconnection to the river). This could contribute to reduce the risks of major flooding in populated areas, enhance the ecosystem services and help protect biodiversity. Further details can be found in Van der Keur et al. (2018).

The second issue is becoming increasingly critical, due mainly to the impacts of drought conditions and low-flows on navigation (since the minimum required draft ranges approximately from 2.80 m to 3.80 m) and on agricultural activities. The introduction of NBS should support limiting the incidence of such phenomena.

Furthermore, a crucial aspect that characterizes the case study, is the need to create an efficient network of stakeholders, contributing to co-define measures and scenarios, capable to support the sustainable and effective implementation of green solutions.

3.2. Individual problem understanding and objectives elicitation in the case study

The methodology for stakeholders' selection described in Section 2 was implemented in the case study. Following the "snowball" sampling methods (see Section 2), we started by interviewing the key actors involved in the management of the water-related risks in the case study. In this case, the starting actor was the Romanian branch of the WWF, because it was already carrying out NBS projects in different areas of the Romania country. Table 4 describes the stakeholders involved in the different phases.

Unfortunately, the efforts done to involve the main local industry of food production were vain. Moreover, local experts and scientists were involved in the process. Nevertheless, they acted as consultants for the NARW and the ANPA. Therefore, we decided to consider them as part of these institutions.

Individual semi-structured interviews were carried out according to the framework described in Section 2.1. Considering that many stakeholders had a rather vague knowledge about the NBS, a simple catalogue of the potentially useful NBS was created and shared with them. Local experts were involved in the development of the NBS catalogue. In order to facilitate the interaction with the stakeholders, the NBS catalogue contained simple examples and avoided integrated solutions – e.g., retentions areas and wetland restoration. Nevertheless, synergies were accounted for in the FCM scenario simulation, as described in Section 3.3. The following NBS were introduced to the stakeholders:

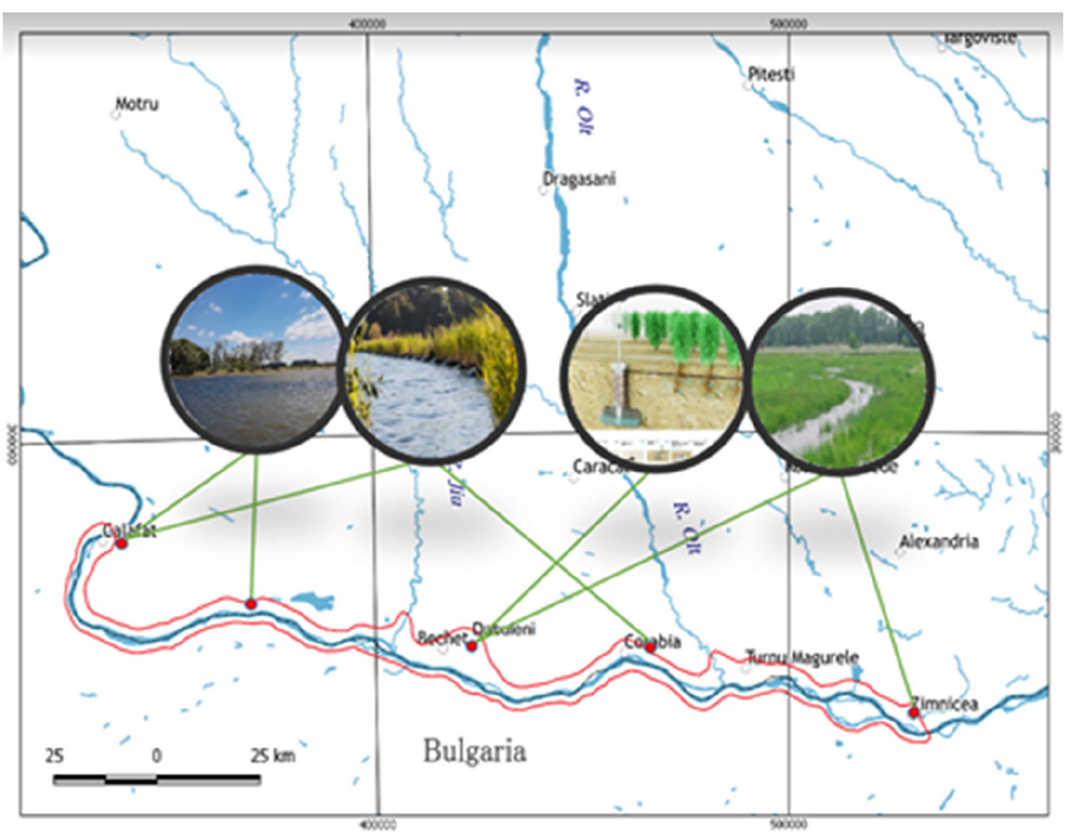

Fig. 5. Study area. The area is located in the lower part of the Danube river, at the border between Romania and Bulgaria. The area has been selected because affected by sever water-related risks.

Table 4
Stakeholders involved in the NBS co-design and evaluation process.

Institution	Role
Municipality of Bistret - Environmental Department	Control of the environmental conditions, particularly in the protected areas
Municipality of Calafat - European Projects Department	Implementation and promotion of policies, strategies, procedures and action plans of the local administration and monitoring of public services and utilities.
Municipality of Corabia	Support to and coordination among several offices, such as the urbanism department, the public servants, the public service for water supply and waste water management.
Municipality of Dabuleni - urbanism department	Development of the local infrastructures (roads, sewage and potable water)
Ministry of Agriculture and Rural Development (MARD)	Responsible to implement the government policies and strategies in the agriculture, food industry, rural development, fishing and aquaculture, land improvement sustainable soil management and connected research activities. Responsible for the implementation of the national rural development program and the EU policies in the agricultural sector. Key role in the implementation of the national strategy for adaptation to climate change, and, thus, for reducing drought impacts.
Municipality of Turnu Măgurele (Local Development Dpt. - Environment Protection Dpt.)	The Local Development Department monitors both the social and the business environment, evaluate and propose actions and activities to be implemented. The Environmental Protection Department is monitoring and evaluating the environmental conditions within the city and propose actions and activities for their improvement.
WWF Romania	Environmental protection activities and educational programs for environment and green economy.
Municipality of Zimnicea - International Projects department	Support for the implementation of measures to reduce the flood risks and to protect the local community against floods. The municipality implements the emergency management plan and develops strategies for the town and guiding documents for key projects (e.g. infrastructure, economy, tourism).
National Administration “Romanian Waters” (NARW)	It a public institution responsible for the management of the waters of the state public domain and the infrastructure of the National System of Water Management (reservoirs, flood protection dykes, canals, inter basin derivations, water intakes and other works).
Romanian National Agency for Fishing and Aquaculture (ANPA)	Monitoring and management of the resources for fishing production and aquaculture. This agency has a role in the implementation of wetland restoration projects.
Municipality of Potelu – representatives of local community	This community has been selected because directly impacted by the implementation of the NBS project.

i) wetland restoration; ii) river renaturation; iii) retention areas; iv) reforestation; v) watershed renaturation. Participants were required to select the most suitable NBS according to their problem understanding, and to describe the expected impacts. Due to their limited knowledge of NBS, the catalogue was not widened during the interaction with the stakeholders. The main concepts and the causal connections were, hence, detected and reported in the FCM. Moreover, the fuzzy weights were assigned to the causal connections. Fig. 6 shows the FCM developed accounting for the narrative collected from two of the involved stakeholders.

The stakeholders' FCM were used to define their perceptions about the most important co-benefits to be produced through the NBS implementation. The FCM analysis methods were implemented at this stage. Specifically, the centrality degree and the impact degree assessment were carried out (see Section 2.1 and the Supplementary material). As already described, the centrality degree was calculated accounting for the complexity of the causal connections of each variable in the FCM (Santoro et al., 2019). The impact degree was assessed by simulating FCM scenarios according to the Eq. (2), and comparing the values of the FCM variable in case of NBS implementation – i.e. setting the value of the NBS to 1 in the state vector – and the values without NBS. The Fig. 7 shows the expected NBS impacts according to the Bistret Municipality FCM.

As shown in Fig. 7, the NBS implementation was perceived capable to produce positive impacts on the socio-institutional and economic variables. Specifically, the stakeholder perceived the process of NBS design and implementation as capable to raise community risk awareness and to enhance the cooperation among different institutional actors. Besides, the reduction of the flood impacts on the agricultural production and the increase of tourism due to the wetland restoration were expected to enhance the community well-being. FCM simulations were carried out for the other stakeholders as well.

As described in Section 2 and in the Supplementary material, the centrality and impact degree were translated into fuzzy linguistic assessment and aggregated. Fuzzy aggregation procedure was implemented (see Section 1.3 in the Supplementary material). At the end of this phase, the most important elements in the stakeholders' problem understanding were defined, as shown in Table 5.

The obtained results were, then, presented and validated during the first stakeholders' workshop. Table 5 shows the differences and similarities in stakeholders' perception about the co-benefits to be produced. It is worth noticing that several stakeholders considered the process of NBS design and implementation as a key driver for enhancing community involvement and institutional cooperation. Moreover, the NBS implementation was expected to have a strong positive impact on the local economy and on the community well-being. The importance degree analysis showed also some differences among stakeholders' objectives. Specifically, it is worth noticing that some stakeholders gave great emphasis on the local ecosystem state as an enabling factor for the local development. Whereas, others gave importance to the traditional economic activities, such as agriculture and fish farming.

The calculated importance degrees of the perceived co-benefits were used to develop the stakeholders' objective functions. For instance, the objective of the WWF was to maximize the following function:

$$F(O)_{wwf} = CA * w_{CA} + IC * w_{IC} + CW * w_{CW} + LE * w_{LE} + ET * w_{ET}$$

In which CA represents the value of the variable “Community Risk Awareness” and w_{CA} represents its weight (i.e. importance degree) in the stakeholder's problem perception; IC is the value of the “Institutional cooperation” and the relative weight; CW is the value of the “Community well-being” and the relative weight; LE represents the “Quality of lake ecosystem”; and ET is the value of the “Eco-tourism”. The other elements in the equation represent the values of the remaining selected co-benefits and the associate weights. The same approach was implemented for defining the objective functions for the other stakeholders.

The stakeholders were, then, required to describe the desirable dynamic evolution of the selected co-benefits. In order to facilitate their task, three main time steps were considered, i.e. short, medium and long term. Considering that the NBS scenarios were based on

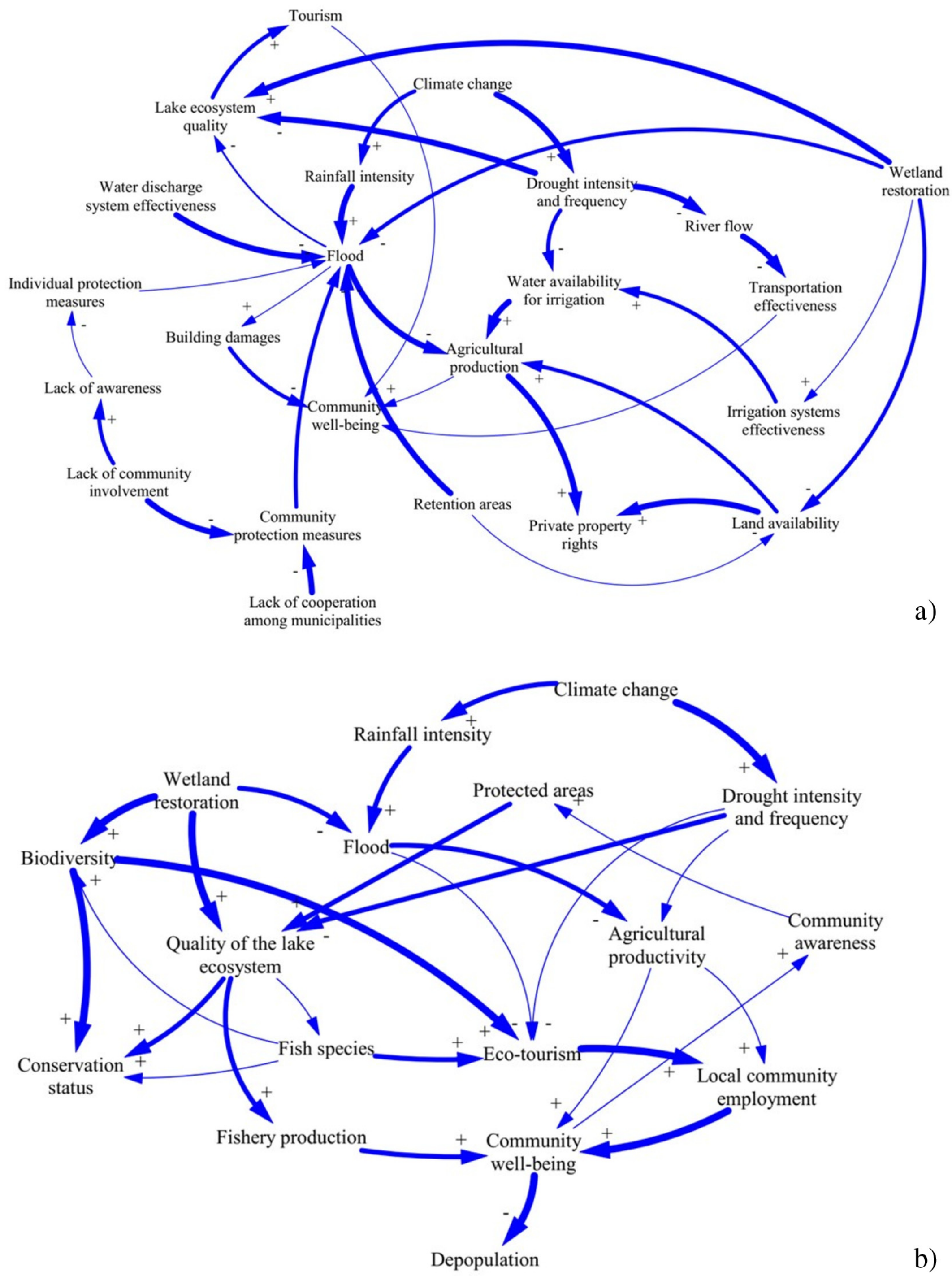

Fig. 6. FCM developed using the stakeholders' interviews: a) Bistret Municipality; b) WWF Romania. The connections are characterized by different width according to the weight assigned by each stakeholder. The polarity of the connections is also represented.

30 years' simulation, we assumed that short term was about 10 years, medium in 20 years, and long in 30 years. Fig. 8 shows the expected evolution of the co-benefits as perceived by the Bistret municipality.

As shown in Fig. 8, the Bistret stakeholder was aware that socio-institutional processes – i.e. risk awareness and institutional cooperation - required time. Therefore, in the early phase of the NBS implementation, these variable decreases, according to the current trend. In the medium and long term, the stakeholder expected to register an increase. Contrarily, the stakeholder was expecting a rather rapid increase of the economic co-benefits and a stable trend for the agricultural production.

Similar inputs were collected by the other stakeholders concerning their perception of the dynamic evolution of the selected co-benefits. The collected inputs were, then, used for detecting and analyzing the trade-offs, as described further in the text. It is worth mentioning that, in few cases, it was not possible to draw the graph of the desirable dynamic evolution of the co-benefits interacting directly with the stakeholders. In these cases, the graphs were solicited using the results of the interviews and, then, validated prior to be used for the trade-offs analysis.

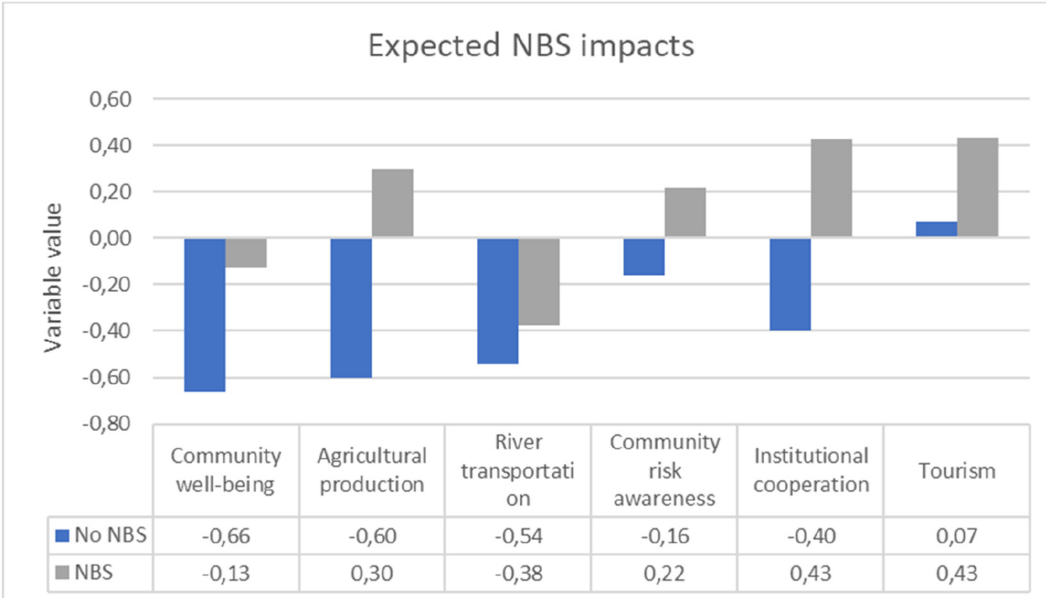

Fig. 7. Graph showing the expected NBS impacts for the Bistret municipality.

Table 5
Stakeholders' perceptions of the expected co-benefits to be produced through NBS implementation.

Stakeholder	Variable	Centrality degree	Impacts degree	Importance degree
Dabuleni Municipality	Institutional cooperation	High	Medium	High
	Agricultural productivity	Medium	Medium	Medium
	River transportation	High	High	High
	Local development	Medium	High	High
Bistret Municipality	Institutional cooperation	High	Medium	High
	Community risk awareness	High	Low	Medium
	Agricultural productivity	Medium	Medium	Medium
	Community well-being	Medium	High	High
	River transportation	Medium	Medium	Medium
	Tourism	Medium	High	High
Calafat Municipality	River transportation	High	Medium	High
	Local development	Medium	Medium	Medium
Corabia Municipality	Community risk awareness	Medium	Medium	Medium
	Institutional cooperation	High	High	High
	Agricultural productivity	Medium	Medium	Medium
	River transportation	High	High	High
Rastul Vechi Municipality	Community risk awareness	Medium	Medium	Medium
	Agricultural productivity	Medium	High	High
	River transportation	Medium	High	High
Turnu Măgurele	Community risk awareness	Medium	Medium	Medium
	Institutional cooperation	High	High	High
	Biodiversity and ecosystem state	Medium	Medium	Medium
	Local development	Low	High	Medium
	River transportation	Medium	High	High
	Community wellbeing	Medium	High	High
WWF Romania	Community risk awareness	High	High	High
	Community well-being	High	High	High
	Quality of the lake ecosystem	Medium	High	High
	Eco-tourism	Medium	High	High
Ministry of agriculture and rural development	Community risk awareness	Medium	Medium	Medium
	Agricultural productivity	High	High	High
	Fish production	Medium	High	High
Romanian National Agency for Fishing and Aquaculture (ANPA)	Fish production	High	High	High
	Biodiversity	High	High	High
	Community wellbeing	Medium	High	High
National Administration “Romanian Waters” (NARW)	River transportation	Medium	High	High
	Community well-being	Medium	Medium	Medium
	Community risk awareness	High	Low	Medium
Municipality of Potelu – representatives of local community	Depopulation	High	Medium	High
	Eco-tourism	High	Medium	High
	Biodiversity	Medium	Medium	Medium
	Fish production	High	Medium	High

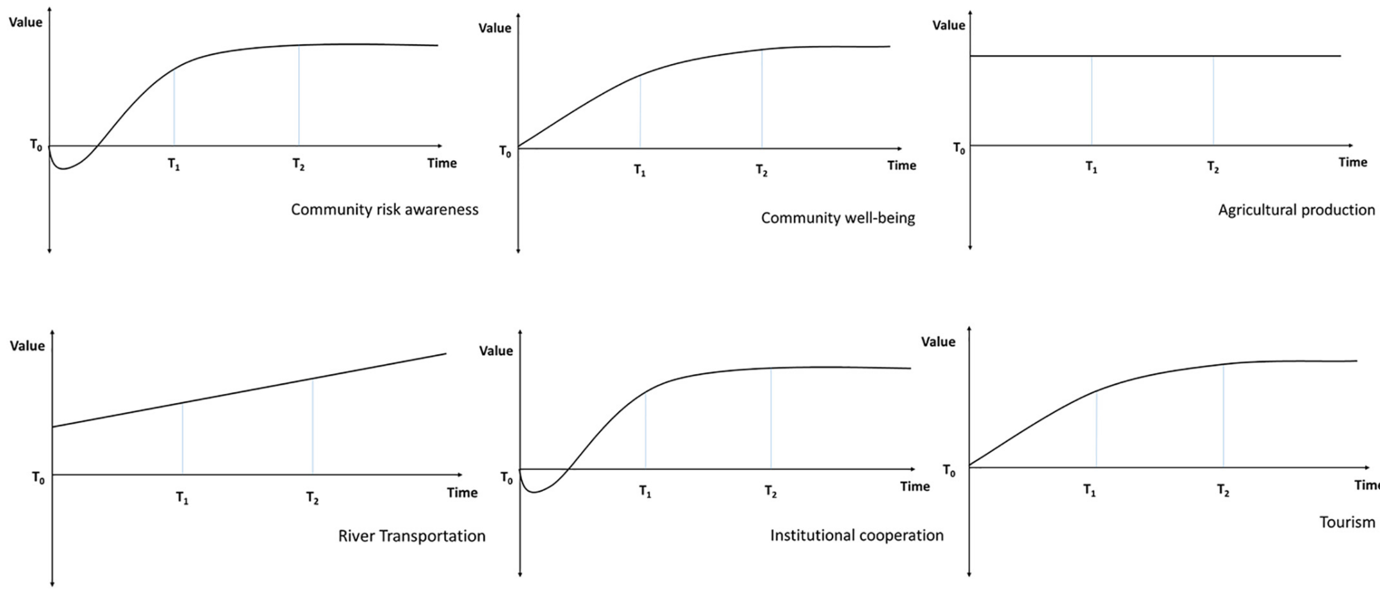

Fig. 8. Dynamic evolution of the "Community Risk Awareness" according to the Bistret municipality.

3.3. FCM aggregation process and scenario simulation

Table 4 shows the differences among the stakeholders' perception about the most important co-benefits to be produced through the implementation of NBS in the study area. This phase of the work was meant to assess if and in which conditions these differences generate trade-offs among the involved stakeholders. To this aim, the individual inputs were aggregated in order to facilitate the debates among the different stakeholders. This phase concerned: i) the development of a shared model for scenarios simulation – i.e. aggregated FCM; and ii) the definition of shared risk management strategies.

3.3.1. Co-definition of the set of actions for risk management

As stated in Section 2, stakeholders' were involved in a group discussion aiming at developing the set of actions to be used as drivers for NBS scenarios simulation. A workshop was organized in Craiova, and the main stakeholders were invited. Table 6 shows the list of NBS and soft actions that were identified during the analysis of the individual FCM.

Participants were, then, required to develop three different sets of actions, integrating NBS and soft actions. They were instructed to include at least two NBS in each strategy, and to select the soft actions among those that, according to their opinion, need to be implemented to facilitate the implementation of the selected NBS. Due to lack of time, only two sets of actions were developed, as shown in Table 7.

These sets of actions were, hence, used for simulating the FCM scenarios. Although "wetland restoration" and "retention areas" were considered as different NBS (see for example Robinson et al., 2010), in the FCM simulation the synergistic effects were accounted for. That is, the wetland restoration had a positive impact on the reduction of flood risks due to its retention capacity, and the retention areas had positive impacts on the biodiversity and ecosystem state due to the possibility to create wetlands in the retention areas.

3.3.2. Aggregated FCM and NBS scenario simulation

The FCM aggregation method described in Section 2.2 and in the Supplementary material was implemented in the case study. Fig. 9 shows the aggregated map for the Lower Danube case study.

In order to be used for developing NBS scenarios, the aggregated map was further discussed with the involved stakeholders in order to validate it and to identify the delays to be introduced in the model. Firstly, clear disagreement among stakeholders' individual FCM (e.g. the same connection was considered by two stakeholders with opposite polarity) were discussed and solved. Secondly, the validation method described in Section 2 was implemented. Therefore, stakeholders were required to assess the FCM capability to describe their own understanding of the risk management problem. During the discussion missing links and variables were identified and added to the aggregated FCM.

Once an agreement was achieved over the topology of the FCM, participants were asked to detect and define the main delays in the FCM. Firstly, they identified the connections subjected to changes in time. These arcs were reported with the delay symbol in the FCM (Fig. 9). Secondly, a group discussion was organized in order to define the weights to be assigned to those arcs in the three time steps, i.e. short, mid and long term. The three adjacency matrixes were developed accordingly. The three obtained adjacency matrices are reported in the Supplementary material (Section 2.2).

The aggregated FCM was, then, used for simulating NBS scenarios. To this aim, the sets of actions developed by the stakeholders (Table 7) were used for defining the initial state vector in the two scenarios.

Table 6
List of NBS and soft actions used during the stakeholders' workshop.

Soft (socio-institutional) actions	Nature-based solution
Capacity building initiatives	Reforestation
Territory control	Retention areas
Institutional cooperation	River renaturation
Insurance policy	Watershed renaturation
State policy for the recovery costs	Wetland restoration
Infrastructure maintenance and development	

Table 7
Integration between NBS and soft actions, as discussed by the stakeholders during the Craiova workshop.

Set of actions	NBS	Soft measures
Set 1	Wetland restoration	Institutional cooperation
	River renaturation	State policy for recovery costs Territory control
Set 2	Retention areas	Infrastructure maintenance and development
	Reforestation	Capacity building initiatives Insurance policy

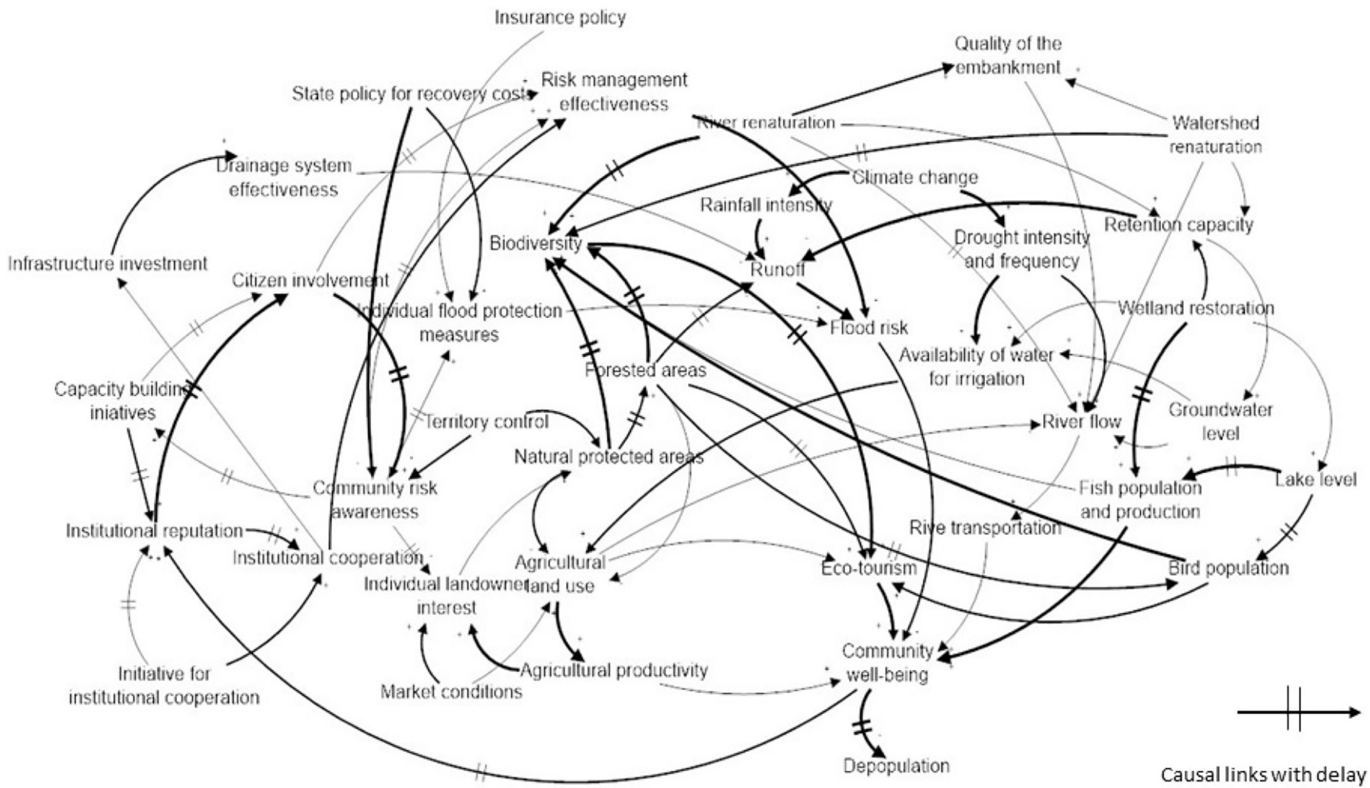

Fig. 9. Aggregated FCM describing the system behavior according to the stakeholders' understanding.

That is, in the first scenario the variable related to "wetland restoration", "river renaturation", "Institutional cooperation", "State policy for recovery costs" and "Territory control" were activated (see Supplementary material). The dynamic FCM scenario simulation as described in Section 2.2 and in the Supplementary material was implemented. Fig. 10 shows the dynamic evolution of the system in scenario 1. For sake of clarity, only the variables selected by the stakeholders as co-benefits are plotted in the graph.

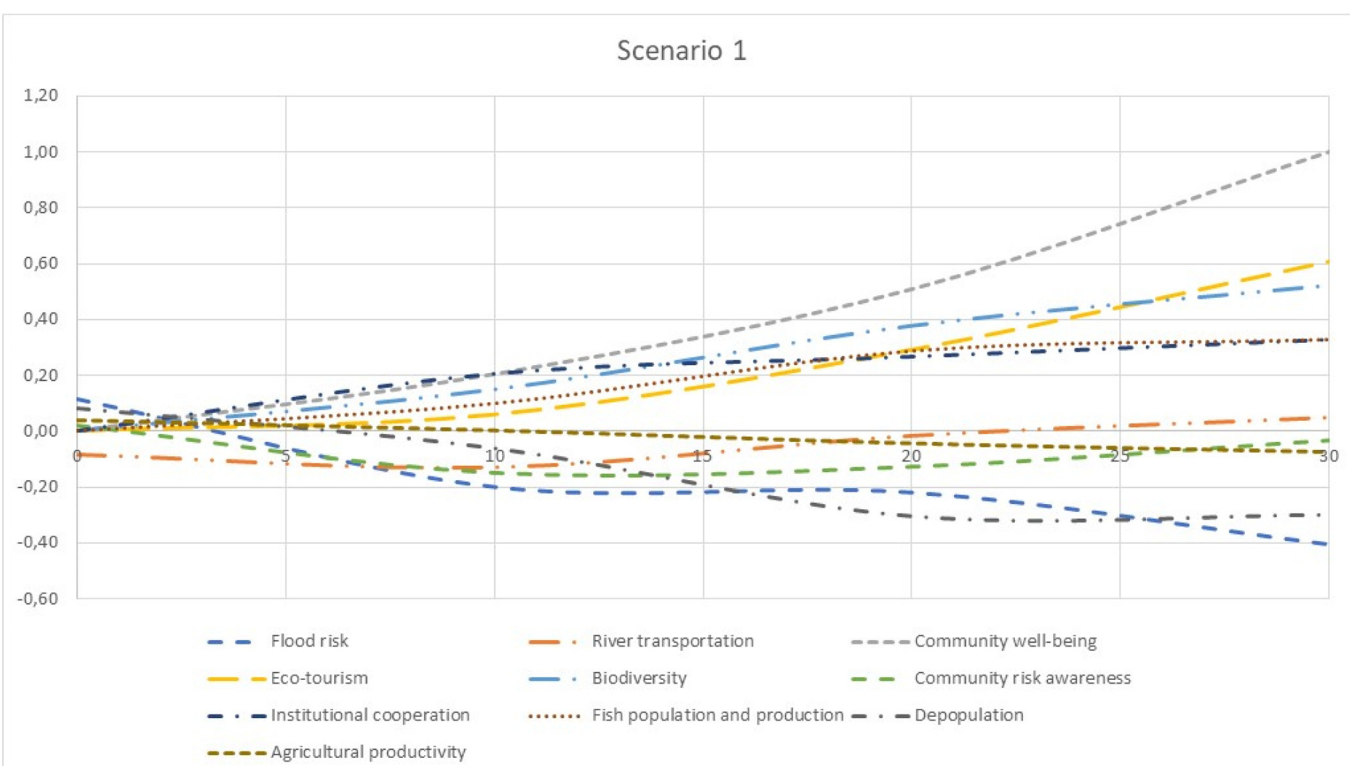

Fig. 10. Co-benefits evolution in scenario 1.

The x-axis represents the time, and the y-axis represents the value of the FCM variables in this scenario. As described in Section 2.1, a threshold function was implemented in the FCM calculation allowing to normalize the values in [−1; 1]. Fig. 10 shows the positive impact of the measures implemented in scenario 1 on the community-well-being. This is mainly due to the expected increase of the biodiversity and, therefore, of the eco-tourism. The decrease of the agricultural productivity, caused by the increase of the natural protected areas, will not affect the community well-being. According to the stakeholders' knowledge, the current agricultural production system – i.e. characterized almost entirely by one big producer, with small repercussion the local employment rate. The river transportation decreases in the early phase of the scenario simulation and, then, slightly increases. This is mainly caused by climatic conditions, which are supposed to remain negative for the whole scenario – that is, high drought frequency – and due to limited effects of the selected NBS on the river flow.

It is worth mentioning that in this scenario the community risk awareness is supposed to decrease in the early phases and, then, slightly increases due to the implementation of the measure "territory control". According to the stakeholders' knowledge, increasing the control of the territory will lead the local communities to perceive the institutions as the unique responsible for the management of the territory, as result of the historical heritage from the communist time. This, in turn, will reduce the community members' awareness about the role that they could play. The community risk awareness will increase in the long term due to the positive impacts of the implemented measures and, thus, the enhanced reputation of the institutional actors.

Fig. 11 shows the evolution of the co-benefits in scenario 2.

The graph shows the negative impacts of selected measures on the co-benefits connected to the biodiversity and eco-tourism. This is mainly due to the expected increase of the cultivated lands, caused by the lack of territory control and the increase of water availability for irrigation purposes. Moreover, the selected NBS are expected to have a lower and slower impact on the biodiversity compared to those selected in scenario 1. Considering the importance of the eco-tourism in enhancing the community well-being, the latter variable will decrease and the depopulation process will increase. The lack of territory control and the implementation of capacity building initiatives will cause an increase of the community risk awareness.

Unfortunately, the results if the FCM-based model cannot be compare with those of the indicator-based approaches because the NBS were not implemented yet. Therefore, data were not available for defining the indicators. Moreover, the FCM is site-specific and its results cannot be compared with indicators developed for other locations.

The results of the two scenarios were presented and discussed with the stakeholders, in order to identify the most desirable one. Participants selected the scenario 1 because of the co-benefits produced in this scenario. Therefore, the trade-off analysis was carried out accounting for the measures to be implemented in the scenario 1. To this aim, the methodology described in Section 2.3 was implemented. The FCM scenarios allowed calculating the value of the objective functions for each stakeholder. To this aim, the simulated values for the FCM variables associate to the co-benefits selected by each stakeholder were accounted for. Then, Eq. (1) was implemented. The following table shows the calculation for the Dabuleni Municipality (Table 8).

Eq. (1) allowed calculating the value of the stakeholder's objective function in the three-time steps. The comparison between the stakeholder's objective function in the simulated scenario and in the desirable one was used for defining if and when the stakeholder perceived a dis-benefit due to the NBS implementation. Similarly, the objective functions for the remaining stakeholders were assessed and compared with the desirable ones. Fig. 12 shows the results of this comparison for all involved stakeholders.

Fig. 12 shows that all involved stakeholders perceived a dis-benefit in the short term. This is mainly because stakeholders over-estimate the effectiveness of the implemented strategy on community well-being and risk awareness in the short term. In two cases, namely Corabia and Rast, the objective function is lower than the expected one in all time steps. This is mainly because these stakeholders gave a high importance degree to the co-benefits "agricultural productivity"

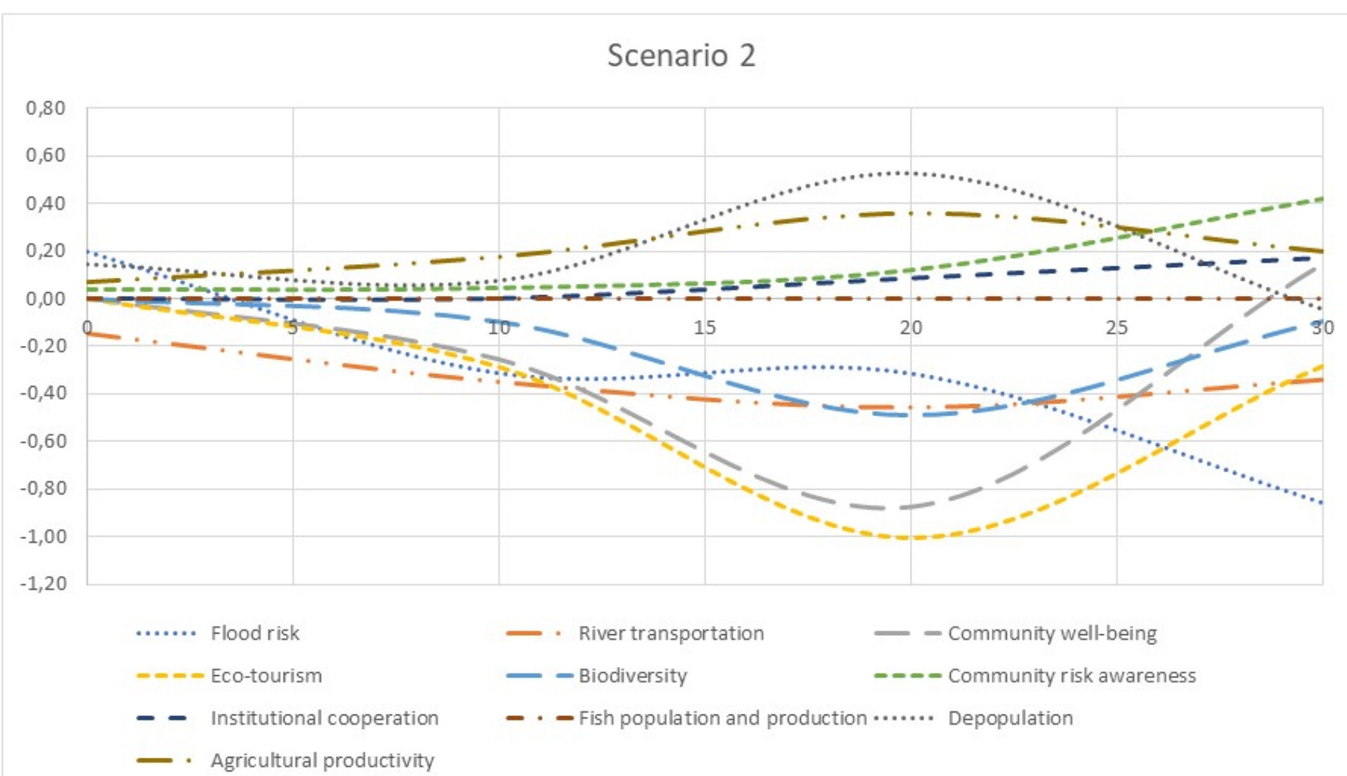

Fig. 11. Dynamic evolution of the co-benefits in scenario 2.

Table 8
Simulated values for the co-benefits defined by the Dabuleni Municipality.

Co-benefits	Weight	FCM scenario		
		Short term	Medium term	Long term
Institutional cooperation	High	0,21	0,27	0,33
Agricultural productivity	Medium	0,01	−0,04	−0,07
River transportation	High	−0,13	−0,02	0,05
Community well-being	High	0,02	0,51	1,00

and "river transportation". The FCM simulation showed that: (i) the former is expected to decrease in the medium and long terms due to the increase of the natural protected areas; and (ii) the implemented NBS was supposed to have a limited impact on the river flow and, consequently, river transportation.

In many cases, the stakeholders perceived a high benefit from the strategy implementation in the long term because of the positive impact of the implemented strategy on the eco-tourism and community well-being. Tables 9a, 9b and 9c show the pairwise comparison among the stakeholders' perceived benefits in the short, medium and long term (see Section 2.3). The distance between two stakeholders was considered here as a measure of the potential trade-off.

As shown in these tables, the distances among stakeholders' perceived co-benefits are quite small in the short term, whereas the distances seem to increase in the long-term. Therefore, the analysis showed that most of the potential conflicts can be expected in the long term, and could involve mainly the stakeholders that assigned a high value to the agricultural productivity.

The results of the trade-offs analysis can be used by decision-makers to prevent potential conflicts and to facilitate the NBS implementation. The results show the importance of raising stakeholders' awareness

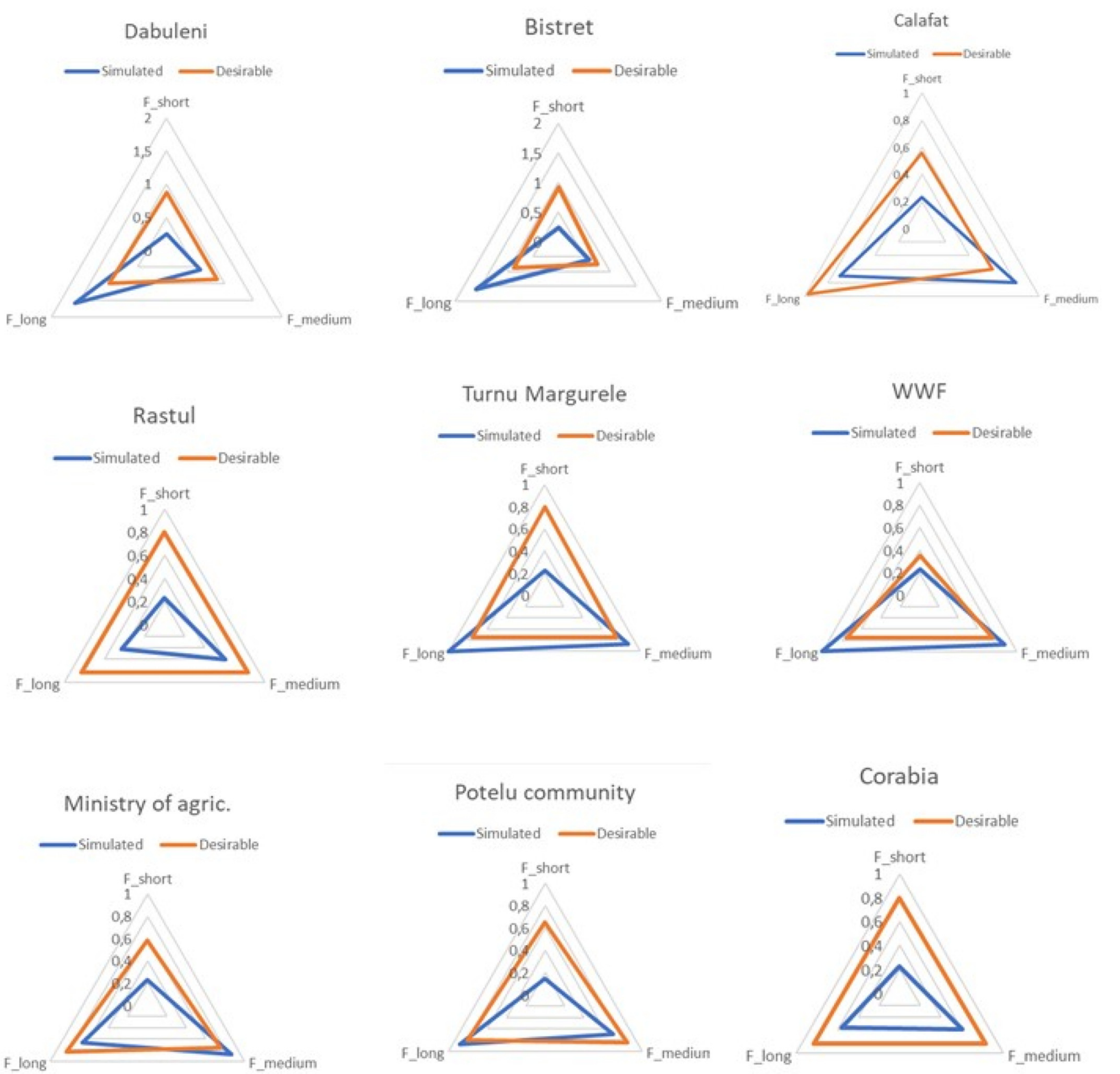

Fig. 12. Comparison between the stakeholders' objective functions in the simulated and desirable scenarios.

Table 9a
Pairwise comparison among the stakeholders' perceived co-benefits in the short term.

	Dabuleni	Bistret	Calafat	Corabia	Rastul	Turnu Măgurele	WWF RO	MARD
Dabuleni	–	0,05	0,29	0,05	0,05	0,07	0,50	0,27
Bistret	0,05	–	0,34	0,34	0,10	0,10	0,55	0,32
Calafat	0,29	0,34	–	0,24	0,24	0,56	0,19	0,02
Corabia	0,05	0,34	0,24	–	0,00	0,02	0,45	0,12
Rastul	0,05	0,10	0,24	0,00	–	0,02	0,45	0,12
Turnu Măgurele	0,07	0,10	0,26	0,02	0,02	–	0,47	0,14
WWF RO	0,50	0,55	0,19	0,45	0,45	0,47	–	0,23
MAFDF	0,27	0,32	0,02	0,12	0,12	0,14	0,23	–

about the great potentialities of the wetland restoration project in creating new community development opportunities due to the eco-tourism. Therefore, interacting with the stakeholders that assigned a high value to agricultural productivity is key for reducing the risk of conflicts over NBS implementation. Moreover, the results demonstrate also that all stakeholders need to be informed in the early stage of the project implementation, in order to make them aware of the time lag needed for producing the expected co-benefits.

4. Discussion

This section is focused on two different, but equally important issues. On the one hand, we assess the suitability of the proposed methodology for eliciting and structuring stakeholders' perception about NBS co-benefits, and for analyzing the potential trade-offs among different stakeholders due to the NBS implementation. This will facilitate the replicability of the adopted methodology. On the other hand, the results of the analysis are used to draw some preliminary conclusions concerning the potential barriers hampering the design and implementation of NBS due to trade-offs and potential conflicts among different stakeholders. Policy suggestions aiming to overcome these barriers are derived from this discussion.

Concerning the first issue, 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; Alves et al., 2019b; Pagano et al., 2019). Compared to the above cited works, the approach described in this article introduce few novelties. Firstly, although several authors emphasized the role of stakeholders' engagement in co-benefits identification (e.g. Calliari et al., 2019; Short et al., 2019), efforts were carried out in this work to analyze the main differences and similarities among stakeholders' problem understandings and to use the results of this analysis in defining the co-benefits. To this aim, the experiences carried out in the Lower Danube case study show the FCM capability to structure the complex cause-effect chains affecting the stakeholders' perception of the risks they have to deal with and of the expected NBS contributions, even in terms of co-benefits production. To this aim, the adopted approach for designing the semi-structured interviews facilitates the building of the individual FCM starting from the stakeholders' narratives. Moreover, the FCM analysis facilitates the identification of the most important elements in the stakeholders' problem understandings. This approach allowed to account for the differences in the way the stakeholders perceive and evaluate the NBS co-benefits. The results demonstrate that ambiguity in defining and valuing the co-benefits produced through the NBS implementation could lead to trade-offs among different stakeholders, as already discussed by Small et al. (2017), Wam et al. (2016). Therefore, the trade-offs analysis requires methods and tools capable to handle the diversity in problem frames among the different stakeholders. The implemented approach allowed us to overcome the main limits of the indicators-based approaches (e.g. Calliari et al., 2019; Kabisch et al., 2016; Raymond et al., 2017), which often neglect the differences among stakeholders' perceptions.

Besides, the results in the Lower Danube demonstrate that the analysis of NBS effectiveness and trade-offs detection cannot ignore the dynamic evolution of the system due to the NBS implementation. Efforts were already carried out to account for the dynamic nature of NBS (e.g. Calliari et al., 2019; Alves et al., 2019b; Pagano et al., 2019). Compared to other methods for dynamic analysis, FCM demonstrated great potentialities in facilitating the interaction with the 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) and Jetter and Kok (2014). The FCM model for scenario simulation was built referring to the stakeholders' knowledge elicited during the early phases of project implementation. Therefore, participants were familiar with the causal connections described in the model and were capable 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 validation phase and the scenario development.

Nevertheless, in order to make FCM suitable for developing NBS-based scenarios, the temporal dimension needed to be integrated in the model. Most of the causal interactions described in the model and affecting the NBS effectiveness and co-benefits production are characterized by non-constant strength, because they describe processes that evolve over time. This is particularly true for the variables related to the natural system – e.g. biodiversity, bird population, forested areas, etc. – and the social system – e.g. community risk awareness. Neglecting the time scale of these processes could lead to erroneous and over-simplified results. In this work, a quasi-dynamic approach based on multiple time steps was implemented. That is, the weight of the causal connections in the FCM could change in time according to the dynamic evolution of the process they describe. Three time steps were referred

Table 9b
Pairwise comparison among the stakeholders' perceived co-benefits in the medium term.

	Dabuleni	Bistret	Calafat	Corabia	Rastul	Turnu Măgurele	WWF RO	MARD
Dabuleni	–	0,12	0,48	0,05	0,05	0,40	0,40	0,40
Bistret	0,12	–	0,36	0,07	0,07	0,28	0,28	0,28
Calafat	0,48	0,36	–	0,43	0,43	0,02	0,08	0,08
Corabia	0,05	0,07	0,43	–	0,00	0,35	0,35	0,35
Rastul	0,05	0,07	0,43	0,00	–	0,35	0,35	0,35
Turnu Măgurele	0,40	0,28	0,02	0,35	0,35	–	0,00	0,00
WWF RO	0,40	0,28	0,08	0,35	0,35	0,00	–	0,00
MARD	0,40	0,28	0,08	0,35	0,35	0,00	0,00	–

Table 9c
Pairwise comparison among the stakeholders' perceived co-benefits in the long term.

	Dabuleni	Bistret	Calafat	Corabia	Rastul	Turnu Măgurele	WWF RO	MARD
Dabuleni	–	0,12	0,86	0,86	0,99	0,34	0,36	0,75
Bistret	0,12	–	0,74	0,74	0,87	0,22	0,24	0,63
Calafat	0,86	0,74	–	0,00	0,23	0,53	0,55	0,11
Corabia	0,86	0,74	0,00	–	0,23	0,53	0,55	0,11
Rastul	0,99	0,87	0,23	0,23	–	0,65	0,67	0,24
Turnu Măgurele	0,34	0,22	0,53	0,53	0,65	–	0,02	0,41
WWF RO	0,36	0,24	0,55	0,55	0,67	0,02	–	0,43
MARD	0,75	0,63	0,11	0,11	0,24	0,41	0,43	–

to, i.e. short, medium and long term. The adopted approach does not require the introduction of "dummy" nodes, with consequent changes in the topology of the map, as suggested by Park and Kim (1995). In case of wide and complex FCM, such as the aggregate one developed in this work, the introduction of "dummy" nodes might result in an even more complex model, with a higher number of nodes, that could be hardly used to support the discussion with stakeholders. Moreover, the adopted method allowed to calculate three sequential state vectors for the FCM and, thus, to detect trade-offs among stakeholders in three-time steps.

Although we are aware that the results described in this work are demo-specific, general conclusions can be drawn concerning the barriers to the NBS implementation due to the trade-offs among the different stakeholders. The most important one concerns the role of soft-institutional measures.

In order to make NBS effective in reducing climate-related risks and producing the expected co-benefits, soft-institutional measures need to be implemented as complementary actions. Nevertheless, some of these measures could provoke trade-offs among the stakeholders. As shown in Section 3, on the one hand, the implementation of the "territory control" facilitates the creation of natural protected areas, because it facilitates the implementation of spatial planning rules, among which the establishment of protected areas by the central government. Hence, it enhances the biodiversity in the study area. On the other hand, this action could have a negative impact on the "community risk awareness", which was one of the co-benefits selected by some stakeholders. Therefore, the analysis of the trade-offs due to the NBS implementation claims for a clear understanding and modelling of the complex cause-effects chains affecting the NBS impacts on the system. Moreover, the socio-institutional actions – i.e. the complementary actions – should be accounted for in the trade-off analysis.

The experiences described in this work showed also some limitations of the implemented approach. Capturing and processing stakeholders' knowledge starting from individual inputs is time consuming and requires substantial efforts by skilled analysts for post-processing the information collected during the individual interviews, as already discussed by Olazabal et al. (2018). Approaches based on group discussion for FCM development require fewer contacts with the stakeholders and enable the cross-cultural exchange among the participants during the debate. Nevertheless, given the main scope of this work, collecting and analyzing individual pieces of knowledge played a key role. Therefore, precautions were taken in order to overcome the drawbacks of the individual-based approach for model development. Firstly, we try to reduce stakeholders' fatigue by collecting all the needed information during short and focused meetings. Moreover, we facilitated the exchange of knowledge among the participants by combining individual interviews with group discussion. Concerning the time-consuming issue, it is worth mentioning that the results of the analysis of the individual inputs were used for setting the ground for an informed and effective group discussion. Therefore, we can affirm that the time spent in collecting and processing individual inputs allowed us to reduce the amount of time needed during the collective phase of our work.

The selection of the stakeholders is a key step in making the process successful. Firstly, because the knowledge elicited by interacting with them is at the basis of the whole process (Jetter and Kok, 2014). Therefore, their representativeness needs to be accounted for during the selection of the stakeholders to be involved. Secondly, the process described in this work is quite long and requires the stakeholders to go through different phases of individual inputs and group discussion. Therefore, the stakeholders' selection should also account for their willingness to commit themselves to the whole process. Efforts are required from the analyst in order to keep the stakeholders interested and motivated for the whole process duration. During our experience, we learned that the "snow-ball" sampling approach was useful for selecting the stakeholders to be involved. Basically, we started interacting with key stakeholders, characterized by a pretty high risk awareness and willing to cooperate. Then, other stakeholders were indicated by them during the interviews. In this way, we were capable to define the set of stakeholders to be involved. Moreover, the identification of the stakeholders' key interests and concerns through the FCM analysis allowed us to enhance the communication with the stakeholders, and to keep them interested during the whole process.

Thirdly, the qualitative nature of the FCM simulations represented a limit of the implemented methodology. As already described in the previous sections, FCM were selected as modelling approach in this work because of its capability to simulate system dynamic, even in case of qualitative causal connections – e.g. the connection between the variables "institutional reputation" and "community involvement" – or when no data are available for defining complex equations, such as those required by other system dynamic modelling approach, such as the Stock-and-Flow. Although the structure of the FCM, based on causal connections, was easily understandable by the stakeholders, and used for supporting the debate, many perplexities were mentioned by the participants concerning the results of the FCM scenario simulations. The participants seemed inclined to prefer quantitative evaluation, rather than qualitative results, specifically when they were required to comment the NBS capability to reduce climate-related risks.

Finally, FCM-based methodology for assessing NBS effectiveness did not allowed us to account for the spatial scale for NBS effectiveness assessment and trade-offs analysis. Several authors (e.g. Howe et al., 2014; Golden and Hoghooghi, 2018; Zhang and Chui, 2019) demonstrated that, although most of the studies are focused on the local scales, NBS impacts could change at different spatial scale. Therefore, trade-offs can occur spatially, i.e. across locations. In order to address this issue, efforts for combining the FCM with more quantitative and spatially distributed modelling approach are already being performed.

5. Concluding remarks

Speeding up the transition process from grey infrastructures toward NBS in managing climate-related risks claims for effective communication among decision-makers and stakeholders. Past experiences demonstrated that effective communication regarding NBS needs to be based on the collection of evidences about NBS effectiveness in producing co-benefits. To this aim, integrated and multi-dimensional assessment frameworks are required. The work done in the Lower Danube demo demonstrated that differences in co-benefits perception could lead to trade-offs among the different stakeholders. A methodology based on a sequential implementation of individual and collective FCM was developed and implemented in this work, in order to support decision makers in detecting and analyzing potential conflicts due to the trade-offs. Introducing the time dimension in the analysis, the developed methodology to provide decision-makers with information regarding: i) the stakeholders that need to be targeted by the communication campaigns (those interested by a potential conflict); ii) the key messages of the communication campaigns; iii) the time steps when the campaigns should be organized in order to enhance their effectiveness.

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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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.136552.

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