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Boosting co-creation of Nature-based Solutions within Living Labs: Interrelating enablers using Interpretive Structural Modelling

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ABSTRACT

Co-creation is at the intersection of Nature-based Solutions and Living Lab concepts, which adopt collaboration and innovation amongst different stakeholders to address complex issues such as climate change. Nature-based Solutions have been increasingly recognized for their potential to address diverse societal challenges in a multifunctional, action-oriented, and contextualized manner. Living Labs have proliferated as a participatory approach for the co-development and co-testing of Nature-based Solutions, particularly in Europe. Nevertheless, there is a persistent challenge regarding enhancing stakeholder engagement, which is recognized as crucial for the implementation of Nature-based Solutions. In this article, we examined ten empirical cases of Living Labs applying Nature-based Solutions to increase climate resilience in European coastal cities. We conducted an Interpretive Structural Modelling and Cross-impact Matrix Multiplication Applied to Classification analysis methodology to systematically analyse and interrelate co-creation enablers. We have identified fifteen enablers to co-create Nature-based Solutions in Living Labs across five levels of influence among each other. A key finding is that 'sharing and learning from real-life examples' and 'opening opportunities for informal inputs' have the most driving power among the studied enablers. Having a robust engagement toolbox also appears to be a crucial point in enhancing co-creation. Exploring the potential of such enablers seems vital to fostering the co-creation of Nature-based Solutions within Living Labs. By understanding how enablers are interlinked and can be prioritized based on their driving and dependence powers, environmental managers can better use their resources and engage with their key stakeholders more successfully.

1. Introduction

Co-creation is at the intersection of Nature-based Solutions (NbS) and Living Lab (LL) concepts, which foster collaboration and innovation to address complex societal challenges such as climate change (Arlati et al., 2021; Lupp et al., 2021a, 2021b; Nunes et al., 2021; Wickenberg et al., 2022; Bradley et al., 2022; Mitić-Radulović and Lalović, 2021; Cousins, 2021). Co-creation entails an iterative decision-making and implementation process leveraging diverse stakeholders (Willems et al., 2020; Toxopeus et al., 2020; Cousins, 2021) through innovative shared governance (Mahmoud et al., 2021a). Citizens and end-users co-produce knowledge and solutions beyond their traditional role of beneficiaries (Mahmoud et al., 2021a; Willems et al., 2022), thus emphasising designing solutions with people rather than for them (Mahmoud et al., 2021a). Co-creation fosters awareness, mutual learning, ownership, trust, and reflexivity while accelerating transformations (Tschersich and Kok, 2022; DeLosRíos-White et al., 2020; Wickenberg et al., 2022; Bradley et al., 2022; Lupp et al., 2021b).

NbS are defined by the European Commission (EC) as "solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience." (Martin et al., 2021, p. 1). Most Paris Agreement

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signatories explicitly link NbS with climate goals, showing the global ambition to mainstream NbS (Martin et al., 2021; Lupp et al., 2021b).

LLs have proliferated as a participatory approach for the co-development and co-testing of NbS (Zingraff-Hamed et al., 2019) and are known for their collaborative governance to effectively address climate uncertainty and diverse barriers to NbS for climate adaptation (Tiwari et al., 2022; DeLosRíos-White et al., 2020). LLs are defined by the European Network of Living Labs (ENoLL) as “user-centred, open innovation ecosystems based on a systematic user co-creation approach, integrating research and innovation processes in real-life communities and settings” (DeLosRíos-White et al., 2020, p. 2). Following the Quadruple Helix Model, LLs involve public sector, industry, academia, and citizens as equal contributors throughout all phases, considering their diverse knowledge, skills, goals, and needs (DeLosRíos-White et al., 2020; Lupp et al., 2021a; Nunes et al., 2021; Rizzo et al., 2021; Wickenberg et al., 2022; Mitić-Radulović and Lalović, 2021; Koefoed, 2019; Noble and Enseñado, 2022).

Even though co-creation is perceived as crucial in the policy and research agendas related to successful NbS projects (Mahmoud et al., 2021a; Nunes et al., 2021; Calliari et al., 2022; Voskamp et al., 2021; Mitić-Radulović and Lalović, 2021), enhancing stakeholder engagement is a persistent challenge (Calliari et al., 2022; Lupp et al., 2021b; Mitić-Radulović and Lalović, 2021). We are therefore interested in investigating co-creation enablers, meaning the factors that make co-creation possible, acting as drivers or opportunities. A research gap exists in understanding how participatory processes are articulated, linking science and policy across disciplines (Hügel and Davies, 2020) and providing decision-makers and practitioners with tools and guidance (Martin et al., 2021; Voskamp et al., 2021; Bradley et al., 2022). While existing research primarily focuses on NbS conceptualisation, impacts, and co-benefits, how it can be achieved via stakeholder participation has received little attention (Wickenberg et al., 2022; Frantzeskaki, 2019b). In particular, lessons learned and guidelines from multiple participatory cases are needed for an evidence-based framework for successful NbS co-creation and citizen engagement (Nunes et al., 2021; Frantzeskaki, 2019b). Lastly, there is no literature on interrelating co-creation enablers and analysing configurational sets, meaning particular arrangements or patterns among related factors (co-creation enablers, in our case).

Our study aims to contribute to science, policy, and practice by providing a multiple-case, evidence-based perspective on enhancing stakeholder engagement and co-creation of NbS through LLs. We seek to offer insights to environmental managers for strategic co-creation, considering how enablers can be linked and prioritised, optimising resource utilization. We analysed ten cases of LLs aiming at increasing climate resilience through NbS as part of the European Union’s Horizon 2020 Research and Innovation project ‘SCORE – Smart Control of the Climate Resilience in European Coastal Cities’ (SCORE, 2023). We have conducted an Interpretive Structural Modelling (ISM) and MICMAC (cross-impact matrix multiplication applied to classification) analysis methodology to answer the following questions:

What configurational sets of enablers explain the enabling of co-creation of Nature-based Solutions (NbS) within Living Labs (LLs), based on multiple cases?

How are co-creation enablers interrelated, and what should be the focus of environmental managers to boost stakeholder engagement and co-creation of NbS?

The article follows this Introduction (Section 1) with a literature review on co-creation enablers related to NbS and LLs (Section 2). Section 3 outlines the research methodology and results, Section 4 elaborates and discusses the findings, and Section 5 brings our concluding remarks.

2. Co-creation enablers

2.1. Identification and prioritisation of co-creation enablers

Firstly, we conducted a literature review to establish an initial list of co-creation enablers of NbS within LLs. We have used the search engines Scopus and Web of Science to search for literature with terms related to nature-based solutions, living lab, stakeholder, and co-creation, and identified a preliminary list of enablers. This process is explained in more detail in Appendix A. Based on the literature, this section explains the most relevant co-creation enablers.

2.1.1. Sharing and learning from real-life examples

Sharing data and lessons learned from real-life cases can be helpful in further improving NbS development based on evidence (Frantzeskaki et al., 2019a; Kabisch et al., 2016), acknowledging good practices (Lupp et al., 2021a; Schmalzbauer, 2018), learning from successes and failures (Frantzeskaki, 2019b; Kabisch et al., 2016), and building on previous dialogues and experiences (Wickenberg et al., 2022). There are several recent online NbS platforms and catalogues which make available experiences of many cities around the world co-creating NbS (Sarabi et al., 2021; Mitić-Radulović and Lalović, 2021; Kabisch et al., 2016), for example Oppla, Urban Nature Atlas, Nature-based Solutions Evidence, Nature4Cities, and Urban Nature Explorer. Such evidence of tangible benefits can inspire stakeholders and make them more aware of NbS’s utility (Tiwari et al., 2022).

2.1.2. Project planning

Project planning is important for a successful project and stakeholder engagement, including a roadmap to follow, clear targets, performance indicators, milestones to be achieved, and identification of key stakeholders (DeLosRíos-White et al., 2020). Skills such as facilitation, planning, organisation, monitoring and following up are required for a co-creation approach (Mahmoud et al., 2021a; Nunes et al., 2021; Wickenberg et al., 2022).

2.1.3. Integrating local, tacit, and expert knowledge

It is valuable to acknowledge, utilise, and leverage stakeholders’ local and tacit knowledge (Sarabi et al., 2021; Frantzeskaki, 2019b; Kabisch et al., 2016). Integrating local knowledge involves transparency, inclusion, and collaboration for a comprehensive co-creation process (Mahmoud et al., 2021a). Changing the paradigm to consider plural understandings of knowledge beyond scientific expertise is crucial to “co-create solutions that are well adapted to local realities and that are both scientifically and socially robust” (Tschersich and Kok, 2022, p. 363). Merging tacit and expert knowledge fosters collaborative action based on a shared vision (Wickenberg et al., 2022) and uses the existing knowledge base, such as successful NbS pioneer cases (Schmalzbauer, 2018). “A large variety of tools have been developed worldwide to support the mainstreaming and uptake of NBSs in cities, ranging from methodologies, software, catalogues, repositories and e-platforms to guidelines and handbooks” (Voskamp et al., 2021, p. 2), which can empower stakeholders and integrate local knowledge.

2.1.4. (Continuous) financial and human resources

Co-creation processes require planned and continuous allocation of financial and human resources so the co-created concept can be developed and implemented (Mahmoud et al., 2021a; Willems et al., 2020; Bradley et al., 2022; Knickel et al., 2019; Bongarts Lebbe et al., 2021). Actors must have the means (time and financial resources) to actively engage in participatory processes (Tschersich and Kok, 2022; Mahmoud et al., 2021b). Financial support can be one of the most critical project enablers (Wickenberg et al., 2022). Similarly, organizing and steering a participatory approach requires the dedication of time and human resources (Arlati et al., 2021; Martin et al., 2021).

2.1.5. Interdisciplinary and cross-sectoral approach

The multi-functional and interdisciplinary inherent characteristic of NbS requires a cross-sectoral approach (Arlati et al., 2021; Frantzeskaki, 2019b; Voskamp et al., 2021; Schmalzbauer, 2018; Lupp et al., 2021b; Knickel et al., 2019; Pascual et al., 2022) and can be a motivator for stakeholders to engage (Tiwari et al., 2022; Nunes et al., 2021). NbS can potentially foster novel organisational structures for cross-sector and cross-scale collaboration (Martin et al., 2021; Bradley et al., 2022). The success of co-creation is influenced by overcoming silo boundaries, stimulating communication and knowledge co-production among policy, practice, and society (Mahmoud et al., 2021a; Bongarts Lebbe et al., 2021; Kabisch et al., 2016). Encouraging a paradigm move from working in silos to cross-sectoral allows tapping into existing high capacities from different departments, increases political support (Wamsler et al., 2020), and safeguards interdisciplinarity, knowledge integration, and NbS learning across borders (Wickenberg et al., 2022; Frantzeskaki, 2019b).

2.1.6. Context-specificity

Suiting the local culture is crucial for the stakeholders (Sarabi et al., 2021) and can enhance trust (Tiwari et al., 2022; Mitić-Radulović and Lalović, 2021) in NbS projects, which should be tailored and contextualized solutions (Lupp et al., 2021a). A co-creation approach should be place-based and reflect on local needs (Mahmoud et al., 2021a; DeLosRíos-White et al., 2020; Wickenberg et al., 2022; Toxopeus et al., 2020). Conducting a cultural mapping, meaning “articulating and making visible the multilayered cultural assets, aspects, and meanings of a place” (Nunes et al., 2021, p. 10), can leverage successful citizen engagement, articulate visions, and build trust in co-creation (Koefoed, 2019; Mitić-Radulović and Lalović, 2021). From a technological perspective, risk models can be designed to consider local issues and context specificities, facilitating proposed solutions’ effectiveness and stakeholder acceptance (Bongarts Lebbe et al., 2021).

2.1.7. Engagement tools

Stakeholder engagement can be increased through guidelines and tools identifying NbS’s potential benefits and beneficiaries (Sarabi et al., 2021). There are diverse engagement types and methods that can foster collaboration, commitment (Mahmoud et al., 2021a; DeLosRíos-White et al., 2020; Bongarts Lebbe et al., 2021; Shahani et al., 2022), and empowerment (Voskamp et al., 2021) of actors. Engagement tools can have several formats, such as walks, games, virtual realities, dialogues, debates, design contests, and more (Wamsler et al., 2020; Arlati et al., 2021; Mitić-Radulović and Lalović, 2021). A robust toolbox of stakeholder strategies is valuable in designing and managing participatory processes (DeLosRíos-White et al., 2020; Pascual et al., 2022; Koefoed, 2019).

2.1.8. Opportunity for informal inputs

Throughout the co-creation process, actors should have the opportunity to give input formally and informally (DeLosRíos-White et al., 2020). Having an overarching strategy with formal and informal mechanisms for collaboration across all project stages benefits co-creation (Arlati et al., 2021). A flexible or ad hoc approach may be necessary to grasp different stakeholders’ views and experiences (Wickenberg et al., 2022; Martin et al., 2021; Bradley et al., 2022). For example, formal public hearings can be combined with informal community activities to reach targeted citizens and build trust and engagement (Willems et al., 2020). Self-governance and bottom-up arrangements warrant different formal and informal interactions, contributing to the inclusion of diverse community capacities, knowledge, needs, and views (Shahani et al., 2022).

2.1.9. Tools for knowledge exchange

Combining traditional and innovative tools facilitates discussions and knowledge exchange among actors (Arlati et al., 2021; Nunes et al., 2021), enabling trust and constructive communication (Mitić-Radulović and Lalović, 2021). Examples of knowledge exchange tools can be digital participation systems, graphical recordings of meetings, models or prototypes, events, hands-on workshops, visual canvas, and more. Learning opportunities can happen directly via the provision of materials (such as documents, newsletters, catalogues, and exhibitions) or trainings and indirectly via site visits, discussing case studies, community mapping, polls, workshops, and public debates (Lupp et al., 2021b; Mitić-Radulović and Lalović, 2021; Mahmoud et al., 2021b). Utilizing different tools reinforces collective learning, including the scientific community and civil society (Bongarts Lebbe et al., 2021).

2.1.10. Open, effective, and consistent communication

Effective and transparent communication fosters ownership among stakeholders and trust in the decision-makers (Tiwari et al., 2022). Open and clear communication channels between all actors are essential for successful project implementation (Mahmoud et al., 2021a) and to keep the stakeholders motivated (DeLosRíos-White et al., 2020). A common understanding of the language around the goals and concepts is crucial (Arlati et al., 2021; Knickel et al., 2019; Mahmoud et al., 2021a). Different communication channels should be used to align with the actors’ relevance and technical capabilities (DeLosRíos-White et al., 2020; Nunes et al., 2021). The communication efforts should be continuous and timely to retain stakeholders’ interest and willingness to participate (Arlati et al., 2021; Wickenberg et al., 2022; Mitić-Radulović and Lalović, 2021).

2.1.11. Dissemination activities

Dissemination activities can boost the LLs’ success in raising attention, recognition, and awareness of good practices (Lupp et al., 2021a). To address current knowledge gaps, several projects make efforts to create, centralize, and facilitate access to targeted information by various actors, including actions to classify NbS, provide guidance to city planners, practitioners, or other interested stakeholders, develop methods to assess impacts, create digital platforms, promote events, and translate scientific outputs into policy briefs (Schmalzbauer, 2018). These dissemination efforts raise awareness of best practices, successful solutions, and lessons learned among experts, policymakers, industry, and citizens (Schmalzbauer, 2018; Kabisch et al., 2016; Mahmoud et al., 2021b).

2.1.12. Shared vision

Stakeholders must develop a shared understanding of both the content (such as what NbS and their benefits are) and the process (how they should collaborate) so that the co-creation approach is valuable to them and allows them to learn from each other (Sarabi et al., 2021). From the early stage, stakeholders should reach a consensus on the key issue to be addressed (DeLosRíos-White et al., 2020). Similarly, defining the common objectives (Arlati et al., 2021) and a clear scope (Lupp et al., 2021a) impact the subsequent steps in developing NbS. Having a common vision is also helpful in overcoming potential resistance (Wickenberg et al., 2022).

2.1.13. Leadership and coalitions of support

Visionary political and local leadership are important in realizing an NbS project (Wickenberg et al., 2022). However, political leadership should be coupled with interested and informed citizens, supported by other stakeholders from NGOs, industry, and academia (Wijesinghe and Thorn, 2021). Leadership may also occur through interest, pressure, coalition advocacy groups, or even “vocal and charismatic individual champions” (Martin et al., 2021, p. 15), acting as agents of change. These can be, for instance, environmental or social organizations, NGOs, or victims of climate-related hazards (Martin et al., 2021).

2.1.14. Open and inclusive process

The success of co-created solutions depends on the open process and continuously including all relevant stakeholders throughout the project, encouraging them to engage in all steps (Mahmoud et al., 2021a). "Participation requires curation and organization to ensure diversity, inclusivity, and activation of urban actors" (Shahani et al., 2022, p. 1184). The openness of the process, together with clarity and transparency, is core to building trust (Nunes et al., 2021), with all stakeholders meeting on equal ground (Lupp et al., 2021a, 2021b). Citizens get motivated to act when they perceive openness from the decision-makers (Frantzeskaki, 2019b). Including the 'unusual suspects', meaning not the same citizens over and over in all projects (which can lead to participation fatigue), creates different fora to co-create NbS and stimulates urban innovation (Frantzeskaki, 2019b).

2.1.15. Community ownership and empowerment

For a long-term commitment of stakeholders, place-based ownership, a sense of belonging, and empowerment should be strengthened through continuous activities in the co-creation process (Mahmoud et al., 2021a). Providing (multiple) direct opportunities for involvement in the project can create a sense of ownership of the solutions (Mitić-Radulović and Lalović, 2021), also reinforcing co-responsibility to maintain these after implementation (DeLosRíos-White et al., 2020; Arlati et al., 2021; Lupp et al., 2021a). For example, creating prototypes and small experiments together with citizens may trigger interest, social cohesion, a sense of place and community, and ownership (Wickenberg et al., 2022; Willems et al., 2020; Frantzeskaki, 2019b; Mitić-Radulović and Lalović, 2021).

3. Methods and results

3.1. Interpretive Structural Modelling (ISM)

ISM is an interactive process that utilises experts' knowledge and experience to capture and systematically structure relationships among specific elements in a comprehensive model, leading to a better understanding of the whole phenomenon and the role of each element (Sarabi et al., 2020; Agi and Nishant, 2017). This method allows fragmented and dispersed knowledge to be visualised in a comprehensive, interactive, and actionable way by modelling variables and structuring their interrelationships, therefore being relevant to multidisciplinary fields such as sustainability (Ahmad and Qahmash, 2021). Despite these several strengths of the ISM methodology, there are also some limitations, which we discuss at the end of Section 4.

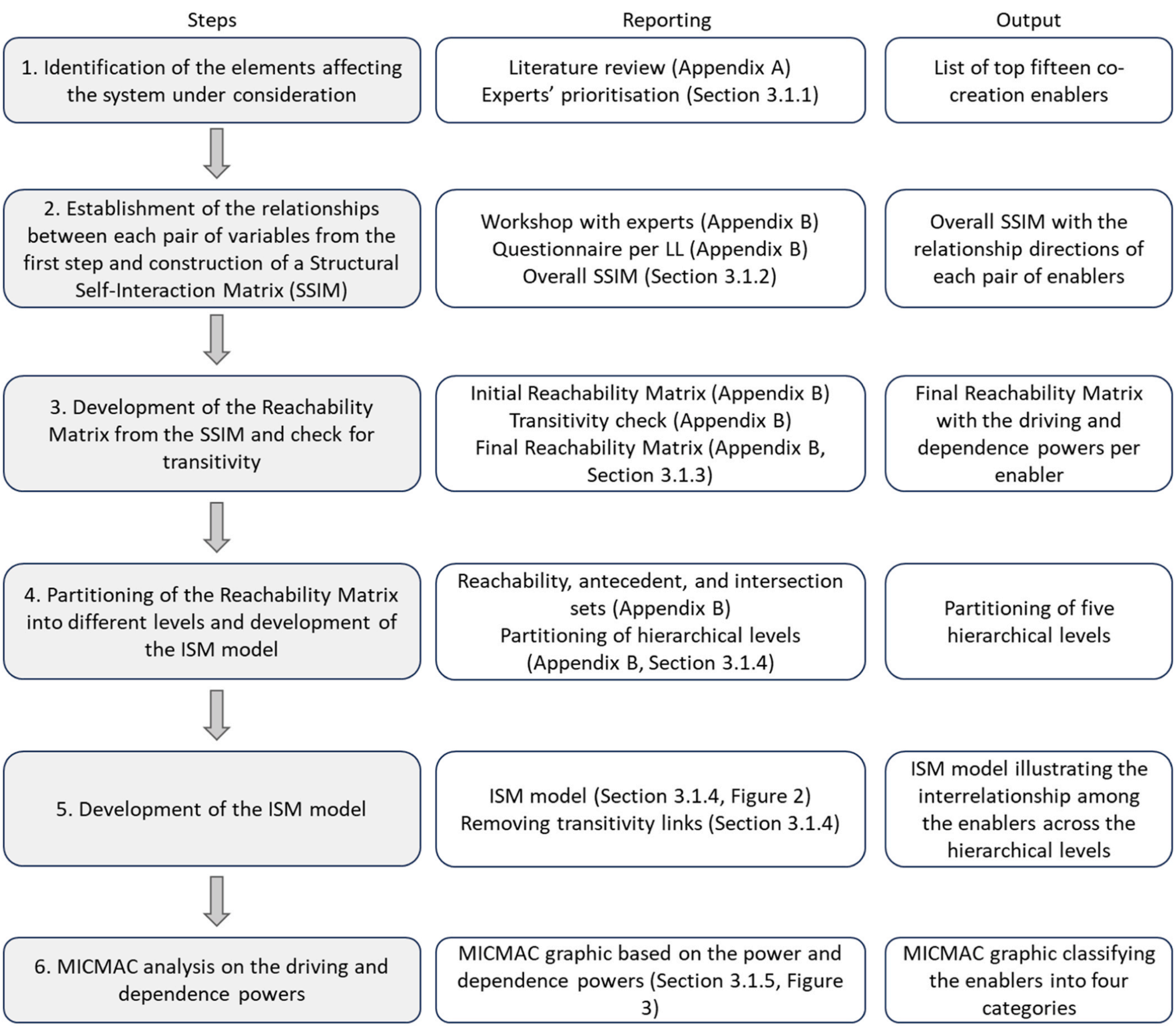

Fig. 1. Steps involved in the Interpretive Structural Modelling (ISM).

Since its proposal in 1973 by Warfield to analyse complex socio-economic systems, ISM has gained popularity and has been applied in many studies (Jabbour et al., 2018). For example, Sarabi has used it to understand the relationship between barriers to NbS (Sarabi et al., 2020) and the adoption of Urban LLs for NbS implementation (Sarabi et al., 2021). Ahmad and Qahmash (2021) reviewed 77 articles and identified the application of ISM in 21 domains, with the highest number of studies in the sustainability field.

The ISM model is particularly relevant for this study because of its characteristic of building a collective understanding of the relationships around experts' knowledge and experience, and we aim to identify lessons learned from multiple participatory cases. Furthermore, ISM works as a group learning process that matches well with the co-creation topic of our research. We investigate ten LLs currently being established and applying NbS to increase climate resilience within the SCORE project. This selection of cases allows us to explore in depth how co-creation occurs in relatively similar systems – European cities facing similar coastal climate hazards and impacts and aiming at increasing long-term climate resilience by designing, developing, monitoring, and evaluating adaptation measures that integrate NbS and smart technologies. The LLs are located in Ireland (Sligo and Dublin), Slovenia (Piran), Turkey (Samsun), Italy (Massa), Spain (Vilanova i la Gertru, Benidorm, and Basque Country), and Portugal (Oeiras) (SCORE, 2023).

The ISM method is applied through sequential steps, illustrated in Fig. 1. First, we identify the elements affecting the system under consideration, meaning the co-creation enablers. We report on the literature review (Appendix A) and the prioritisation done by our respondents (experts and LL team members within the SCORE project, Section 3.1.1), providing a list of the top fifteen co-creation enablers. Second, we establish the relationships between each pair of variables from the previous step and construct a Structural Self-Interaction Matrix (SSIM). Here, we report on the workshop conducted with the respondents, the questionnaire done per LL (Appendix B), and the overall SSIM (Section 3.1.2). Third, we develop the Reachability Matrix from the SSIM and check for transitivity (Appendix B), producing the Final Reachability Matrix with the driving and dependence powers per enabler (Section 3.1.3). Fourth, we partition the Reachability Matrix into different levels, including establishing the reachability, antecedent, and intersection sets (Appendix B). Fifth, we develop the ISM model, illustrating the interrelationship among the enablers across the hierarchical levels (Section 3.1.4 and Fig. 2). Lastly, we conducted a MICMAC analysis on the driving and dependence powers, producing a MICMAC graph classifying the enablers into four categories (Section 3.1.5 and Fig. 3). The subsections below present the results per step.

3.1.1. Identification of the elements (or variables) affecting the system under consideration

To identify the co-creation enablers, we first conducted a literature review (presented in Section 2 and further explained in Appendix A). Secondly, we conducted an in-person workshop on 15 June 2023 to discuss the 27 most cited enablers from the literature (available in Appendix A) with 50 technical experts and team members of the ten LLs within the SCORE project. During the workshop, the participants validated and prioritized the most relevant enablers in their experience, producing a final list of fifteen enablers (Table 1), which are used in the following ISM steps.

3.1.2. Establishment of the relationships between each pair of variables from the first step and construction of a Structural Self-Interaction Matrix (SSIM)

To determine the pairwise relationship between co-creation enablers, we first conducted a workshop on 15 June 2023 (mentioned in step 1). During the workshop, we had thirty representatives from the ten LL core teams. They worked in six mixed groups of 5 participants (containing people from different LLs) to discuss the potential relationships among pairs of co-creation enablers, filling in a draft matrix.

Table 1
Enablers for co-creating Nature-based Solutions through Living Labs. Rank made by our respondents during the workshop.

Rank	Enabler
E1	Sharing and learning from real-life examples
E2	Project planning
E3	Integrating local, tacit, and expert knowledge
E4	(Continuous) financial and human resources
E5	Interdisciplinary and cross-sectoral approach
E6	Context-specificity
E7	Engagement tools
E8	Opportunity for informal inputs
E9	Tools for knowledge exchange
E10	Open, effective, and consistent communication
E11	Dissemination activities
E12	Shared vision
E13	Leadership and coalitions of support
E14	Open and inclusive process
E15	Community ownership and empowerment

Between June and July 2023, an open-ended questionnaire was sent via e-mail to the core teams of the ten LLs, asking them to develop a preliminary Structural Self-Interaction Matrix, now also indicating the direction of each pairwise relationship among the co-creation enablers. Out of the ten LLs, nine fully completed the questionnaire and were considered for this step. Compiling the responses from all nine LLs (further detailed in Appendix B) resulted in the overall Structural Self-Interaction Matrix (SSIM). Table 2 shows the relationship between each pair of enablers, using as symbols:

"O" if the enablers are not directly linked,

"V" if the enabler in the horizontal line (i) affects the enabler in the vertical line in the table (j),

"A" if the enabler in the vertical line (j) affects the enabler in the horizontal line in the table (i), or

"X" if both enablers affect each other.

The open-ended questionnaire was composed of two parts. In the first part, as explained above, we asked the LL core teams to indicate whether or not and in which direction each pair of co-creation enablers are related in their experience. In the second part, we asked open-ended questions to collect more qualitative insights. These included: a) which are the top most useful enablers in their experience, with examples; b) tips or tricks they would give to other LLs to boost co-creation and stakeholder engagement; c) additional remarks. These qualitative insights are included in Section 4. The results were discussed and validated with the ten LLs on 16 February 2024.

3.1.3. Development of the Reachability Matrix from the SSIM and check for transitivity

The details of this step are reported in Appendix B. Following the standard ISM steps, we transformed the SSIM into an initial Reachability Matrix by replacing the symbols with binary numbers 0 and 1. Next, we checked for transitivity, an assumption that if A is related to B and B to C, therefore A must be related to C, to generate the final Reachability Matrix. The final Reachability Matrix (Table 3) reflects the driving and dependency powers of each enabler. The driving power is the total of enablers (including itself) that may be supported (influenced) by the specific enabler. In contrast, the dependence power is the number of enablers (including itself) that may support this certain enabler.

3.1.4. Partitioning of the Reachability Matrix into different levels and development of the ISM model

Based on the final Reachability Matrix, we have established antecedent and reachable sets of enablers for each of the fifteen co-creation enablers and intersection sets, in which the enablers are common in both sets. Partitioning of levels allows us to determine the importance level of each enabler of co-creation. We obtained five levels in this step, detailed in Appendix B and visualized in Fig. 2. The level of relative importance

Table 2
Structural Self-Interaction Matrix (SSIM).

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15
E1		V	O	O	V	O	V	V	V	O	V	V	O	O	V
E2			O	O	O	A	O	O	O	O	V	A	O	O	O
E3				O	V	X	O	A	V	O	V	V	O	V	X
E4					O	O	O	O	O	O	O	O	A	O	O
E5						O	A	A	X	O	A	V	O	A	V
E6							V	O	V	O	X	X	O	V	X
E7								X	V	V	V	V	O	V	O
E8									O	O	V	V	O	V	V
E9										X	V	O	O	V	O
E10											X	V	O	V	V
E11												V	O	A	V
E12													A	X	O
E13														O	O
E14															X
E15															

Table 3
Final Reachability Matrix. DEP = dependence power. DRP = driving power. The number “1” indicates that the enabler in the horizontal line (i) affects the enabler in the vertical line (j) in the table. The number “0” indicates otherwise - the enabler in the horizontal line (i) does not affect the enabler in the vertical line (j) in the table. The number “***1****” (with bold, italic, and starred characters) indicates a change in the table due to the transitivity assumption.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	DRP
1	1	1	1*	0	1	1*	1	1	1	1*	1	1	0	1*	1	13
2	0	1	0	0	1*	1*	0	0	0	1*	1	1*	0	0	1*	7
3	0	1*	1	0	1	1	1*	0	1	1*	1	1	0	1	1	11
4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
5	0	1*	1*	0	1	1*	0	0	1	1*	1*	1	0	1*	1	10
6	0	1	1	0	1*	1	1	1*	1	1*	1	1	0	1	1	12
7	0	1*	1*	0	1	1*	1	1	1	1	1	1	0	1	1*	12
8	0	1*	1	0	1	1*	1	1	1*	1*	1	1	0	1	1	12
9	0	0	0	0	1	1*	0	0	1	1	1	1*	0	1	1*	8
10	0	1*	1*	0	1*	1*	0	0	1	1	1	1	0	1	1	10
11	0	1*	1*	0	1	1	1*	0	1*	1	1	1	0	1*	1	11
12	0	1	1*	0	1*	1	1*	0	1*	0	1*	1	0	1	1*	10
13	0	1*	0	1	0	1*	0	0	0	0	0	1	1	1*	0	6
14	0	1*	1*	0	1	1*	0	0	1*	1*	1	1	0	1	1	10
15	0	1*	1	0	1*	1	1*	0	1*	0	1*	1*	0	1	1	10
DEP	1	13	11	2	13	14	8	4	12	11	13	14	1	13	13	

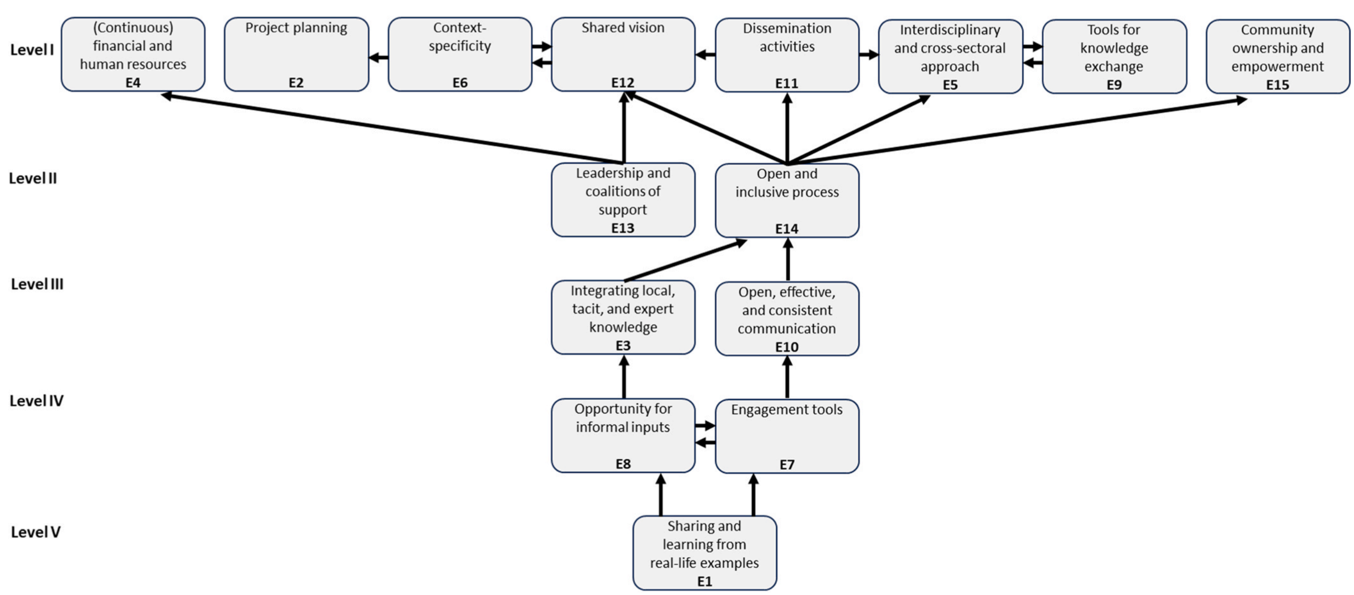

Fig. 2. ISM model: hierarchical structural model of interdependent enablers for co-creating Nature-based Solutions in Living Labs.

increases from the fifth to the first level.

Based on the partitioning of levels, we drew the hierarchical structural model. For this step, we remove the transitivity links. The results show that the most dominant enabler, on the fifth level, is E1 ‘Sharing and learning from real-life examples’. At the first level, we have E2 ‘Project planning’, E4 ‘(Continuous) financial and human resources’, E5

'Interdisciplinary and cross-sectoral approach', E6 'Context-specificity', E9 'Tools for knowledge exchange', E11 'Dissemination activities', E12 'Shared vision', E15 'Community ownership and empowerment', which are the most dependent enablers. The other enablers are situated in the intermediary levels. The ISM model is shown in 2, illustrating the interrelationships among the co-creation enablers, which are represented by arrows. Each enabler at a higher level is directly influenced by at least one enabler at the level immediately below and indirectly by many others in the other levels below.

3.1.5. MICMAC analysis on the driving and dependence powers

We conducted a cross-impact matrix multiplication applied to classification (MICMAC) analysis (Duperrin and Godet, 1973), to assess every enabler's driving and dependence powers. The driving power refers to the number of enablers a specific enabler may influence, while the dependency power is the total of enablers that may influence this certain enabler. The objective of applying a MICMAC analysis is to find leverage points, identifying which enablers have most potential to affect the system and therefore should be prioritized by environmental managers aiming at boosting co-creation, with limited resources. The input for this analysis is the Final Reachability Matrix, reported in Appendix B. The result is a two-dimensional graphic (Fig. 3) classifying the enablers into four categories:

- Quadrant IV - 'independent' or 'driving' factors: enablers in the upper-left quadrant. These enablers have high driving and low dependence powers, and influence most of the other enablers in the system, meaning they are crucial to understanding how the system (interrelationships among co-creation enablers) works. Enablers E1 and E8 are present in this category.
- Quadrant III - 'linkage' factors: enablers in the upper-right quadrant. These enablers have both high power and high dependence powers simultaneously and are unstable. The more influential enablers' actions rely on these 'linkage' enablers, meaning any action on them can strengthen or weaken the extent of the effect of the other factors, creating a feedback mechanism in the system. Most enablers pertain to this category: E3, E6, E7, E9, E10, E11, E12, E14, and E15.
- Quadrant II - 'dependent' factors: enablers in the lower-right quadrant. These enablers have low power and high dependence powers. Their effect is highly influenced by 'independent' and 'linkage' factors. Only enabler E2 is situated here.
- Quadrant I - 'autonomous' factors: enablers in the lower-left quadrant. These enablers have both low driving and low dependence powers. They are a bit disconnected from the system and do not strongly improve or diminish the effect of the other enablers. Two enablers are positioned in this category: E4 and E13.

4. Discussion

The analysis reveals two key enablers to co-create NbS within LLs, located in Quadrant-IV (Fig. 3) and classified as 'driving enablers': E1 'sharing and learning from real-life examples' and E8 'opportunity for informal inputs'. These enablers have a strong driving power in affecting all other enablers. For example, the Sligo LL team highlighted the effect that E1 has on E12 'shared vision' and E13 'leadership and coalitions of support': "*In our experience, the use of real-world examples, particularly case studies, is a valuable co-creation enabler when it comes to the task of developing a shared vision. This is because many members of our communities know they want to bring out changes, but feel they lack the technical expertise to truly inform the decision. By showing examples of how other areas have tackled the same problems, communities tend to find it easier to visualize how similar measures could work in their own communities. Furthermore, political and leadership buy-in for innovative projects can often be more easily achieved when there are proven success stories*". The LL in Sligo is exploring NbS such as afforestation, peatland and wetland restoration, and dune management, to address hazards as coastal floods and sea-level rise. The LL team from Gdansk is investigating water parks, retention ponds, open green spaces, and planting trees to deal with pluvial and coastal flooding. They also recommended focusing on E1 to influence E8, E7 'engagement tools', E11 'dissemination activities' and

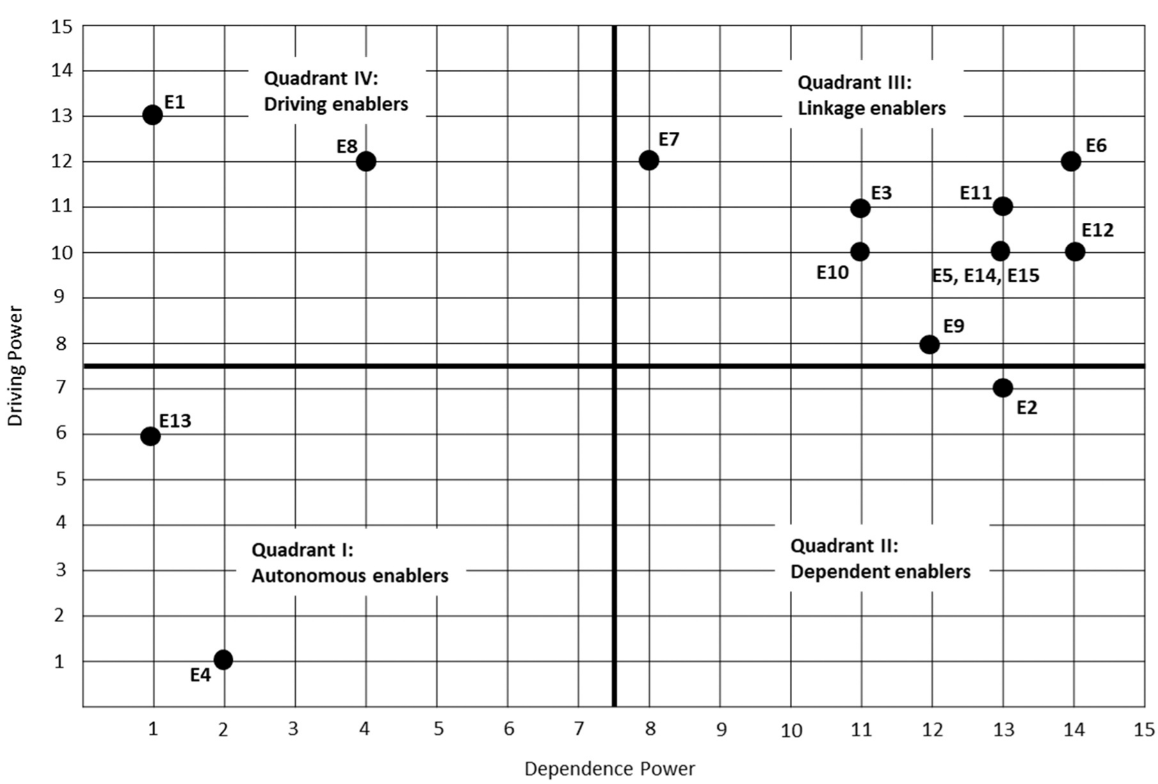

Fig. 3. MICMAC analysis: driving and dependence power diagram.

E3 'integrating local, tacit, and expert knowledge', which have been fruitful in their experience.

The LL in Piran is focusing on winter coastal flooding, storm surge, and summer drought and heatwaves (Kumer et al., 2022). They are considering planting trees, renovating water wells, and combining trees, urban farming, and rain garden, as potential NbS. The team stressed that E1 is crucial for E15 'community ownership and empowerment': "*local community will participate in LL only if they see any tangible result*".

We also identified a relation among the two 'driving enablers', with E1 at the fifth level in the ISM model (Fig. 2), indicating its major importance in the system, influencing E8 at the fourth level. Sharing data, experiences, and lessons learned allows stakeholders to provide their inputs informally. Interestingly, both key enablers are very practical in kind. Focusing on these two enablers is crucial for a strategic approach to co-creation, as any action on them may boost the effect of all the other ones.

Many enablers were positioned in Quadrant III (Fig. 3) and were classified as 'linkage enablers', meaning they are strongly interconnected and may have a feedback effect among each. Many of these enablers (namely E5, E6, E9, E12, E11, and E15) were placed on the first level of the ISM model (Fig. 2), but because these also have a high driving power, they are classified as 'linkage'. For example, E6 'context-specificity' affects the project planning process, the use of engagement and knowledge exchange tools, open and effective communication, and an inclusive process. It both affects and is affected by integrating local and tacit knowledge, a shared vision, dissemination activities, and community ownership and empowerment. For instance, the LL team in Oarsoaldea stated "*The specificity of the context directly affects having a shared vision. Sharing a specific context and similar problems, limitations or challenges makes it very likely that the vision of it, which different agents may have, is similar and/or convergent.*" Oarsoaldea is exploring open green spaces, planting trees, and reforestation of riverbanks to address river flooding and heat waves.

Among the 'linkage enablers', we highlight E7 'engagement tools', which has a high driving power and a lower dependency power than the other enablers in this group, being positioned very close to Quadrant IV. In the ISM model (Fig. 2), E7 is at the fourth level, showing its importance. The LL team from Oeiras, which is assessing planting indigenous species, river network maintenance, and river regularization, among other NbS to address a flooding hazard, emphasized the link between E7 and E11 'dissemination activities'. "*By utilizing effective engagement tools, such as interactive workshops and digital platforms, and combining them with a robust dissemination strategy, CCLLs can reach a broader audience and raise awareness about the co-creation initiatives. This combination enhances stakeholder participation and knowledge sharing.*"

E7 is closely connected to E8 (both at the 4th level in the ISM model), with a reciprocal influence. On the one hand, opening room for informality encourages the inclusion of more diverse types of stakeholders with different knowledge, views, and capacities, contributing to the success of the application of engagement tools. On the other hand, having a robust and diverse set of engagement tools contributes to the design and management of the participatory process, giving opportunities for informal inputs. In the Benidorm LL, the team is exploring floodable parks, river network maintenance, and river regularization to address flooding. They explained the effect of E8 in E7 in their experience: "*Participation tools should not be a barrier for citizens to express themselves freely. Informality should be encouraged at this stage of the process since citizens do not have the technical knowledge or technological tools to pass them on to policymakers*". They further stated the influence of E7 and E8 in E15 'Community ownership and empowerment': "*Participation tools are closely connected to community empowerment, as this is a way to express yourself freely about a problem that may affect you*".

Only one enabler was classified as a 'dependent enabler' in Quadrant II (Fig. 3): E2 'project planning'. E2 was the second enabler in the rank made by the experts, showing its importance to them. In the MICMAC, it was located very close to Quadrant III, indicating a medium driving power. However, even though project planning is essential for the success of a project and for engaging stakeholders, the study shows that it strongly depends on other factors, which is visible through its position at the first level in the ISM model (Fig. 2). This means that having the right skills, such as facilitation, planning, organization, and monitoring, is not enough to ensure co-creation. The development (and achievement) of a roadmap, clear targets, and milestones depends on many enablers, such as following an interdisciplinary approach and building a shared vision. The LL from Vilanova i la Gertru is exploring a combination of multiple NbS, including rehabilitating of riverbanks, riverbed restoration, and increased riverbank height, to protect their coastal city against flooding. The team mentioned that "it is very important to consider interdisciplinarity, dialogue, and tapping into existing capacities and strengths in different sectors to develop an effective project plan implementation". The Benidorm LL team also highlighted that having a clear problem definition and objectives and integrating local knowledge have an essential effect on the project planning.

Lastly, two enablers were situated in Quadrant I (Fig. 3), as 'autonomous enablers': E13 'leadership and coalitions of support' and E4 '(continuous) financial and human resources. E4 has the lowest driving and dependence powers among all enablers analysed in this study. This category of enablers is relatively disconnected from the system. They have less influence on the other enablers and are also difficult to be affected by actions in the other ones. Both these enablers are political and institutional in kind and are external to the LLs, so, understandably, they are more difficult to influence. Still, the allocation of resources is commonly known as crucial to any project, as illustrated by the Oeiras LL team: "'*allocation of (continuous) financial and human resources' is one of the most important enablers with great influence in project planned activities and their accomplishment and all the activities that can be done in the LL*". Thus, we would expect E4 to have a higher driving power and a more direct link to other enablers.

4.1. Theoretical implications for environmental science

Our multiple empirical cases added new insights into how co-creation of NbS within LLs occurs in practice, how such enablers are interrelated, and which seem to be the most powerful (driving) enablers. We highlight three main contributions from our study to the existing body of literature.

First, we find compelling that E1 'Sharing and learning from real-life examples' is the enabler with the highest driving power. It was also the top enabler in the experts' prioritization. However, it was much lower in the rank of citations in the reviewed literature, in fifteenth place. Existing literature stresses the relevance of sharing data and lessons learned from empirical cases to improve NbS development based on evidence (e.g., Frantzeskaki et al., 2019a, 2019b; Kabisch et al., 2016; Wickenberg et al., 2022), and presents a gap in identifying lessons learned from multiple cases for successful NbS co-creation (Nunes et al., 2021; Frantzeskaki, 2019b). However, it does not explore the driving role of sharing and learning from the examples in further boosting other (many) co-creation enablers. Several authors (Sarabi et al., 2021; Mitić-Radulović and Lalović, 2021; Kabisch et al., 2016) highlight the existence of diverse NbS platforms and catalogues. Further research could explore, for instance, how such platforms are (or could be) used to foster stakeholder engagement.

Second, E8 'opportunity for informal inputs' seems essential to fostering NbS co-creation and influences the other enablers in the process, even though it was quite low (25th place) in our reviewed literature. Some authors (Arlati et al., 2021; DeLosRíos-White et al., 2020) mention that an approach combining formal and informal mechanisms for collaboration benefits co-creation and that a flexible approach may be needed to grasp the diverse views of stakeholders (Wickenberg et al., 2022; Martin et al., 2021; Bradley et al., 2022). How such flexible approaches take place in practice in NbS projects fostering informal inputs, and how the opportunity for these inputs further stimulate other co-creation enablers, such as the 'integration of local, tacit, and expert knowledge' (E3), an 'interdisciplinary and cross-sectoral approach' (E5), or 'community ownership and empowerment', would be interesting to investigate.

And third, the allocation of financial and human resources is commonly cited in the literature as an enabler for participatory processes (Mahmoud et al., 2021a; Willems et al., 2020; Bradley et al., 2022; Knickel et al., 2019; Bongarts Lebbe et al., 2021) and highly ranked (4th) by the experts in our cases. We were, therefore, surprised with its positioning as an autonomous enabler. Future research could be conducted to further explore the direct and indirect roles of resource allocation in co-creation enablers, for example through Structural Equation Modelling (SEM) studies, utilizing a large data set from previous NbS and LL projects.

4.2. Implications for policy and environmental managers

The study shows that sharing good practices and lessons learned from previous experiences can promote opportunities for informal inputs, and both these enablers can boost the whole co-creation approach. For example, bottom-up arrangements with formal and informal interactions contribute to a more inclusive process considering diverse community knowledge, capacities, and perspectives (Shahani et al., 2022). There are multiple online NbS platforms and catalogues in which cases from all over the world are available (Sarabi et al., 2021; Mitić-Radulović and Lalović, 2021; Kabisch et al., 2016). Similarly, several engagement tools and toolkits (e.g., UNALAB Tools for Co-creation and IHS Co-create Your City) can promote stakeholder collaboration and commitment (Mahmoud et al., 2021a; DeLosRíos-White et al., 2020; Bongarts Lebbe et al., 2021; Shahani et al., 2022). Project managers and policymakers can make further use of such platforms and tools to inspire and engage stakeholders based on concrete evidence. Prioritizing and focusing the (limited) resources from LLs on the key enablers identified seem quite strategic in advancing the co-creation of NbS.

Our results also indicate that even though the experts highly ranked project planning as an essential focus for them, working on a good plan alone is not enough to ensure co-creation. This suggests that environmental managers should also pay close attention to other related enablers, such as fostering an interdisciplinary approach and building a shared vision.

4.3. Limitations

Despite several contributions from our research, there are some limitations. The ISM method only covers a limited number of variables to build an understandable model and does not give weight to variables or relationships. Some enablers identified in the literature were not included in the model based on our empirical ranking (see Appendix A), due to the limitation on the number of variables, but would be worth exploring in future research. For example, 'fostering trust, accountability and legitimacy', 'co-producing knowledge', 'prototyping and experimenting', and 'having favourable legal conditions' are co-creation enablers frequently mentioned in the literature but have not made it into our top fifteen and entered the ISM analysis.

Also, the results might be biased by the knowledge and experience of the experts who participated in the process. The fact that our cases and experts are within the same project and within the framework of the larger EU Horizon 2020 funding mechanism may impact how the experts prioritized and interrelated the enablers. Furthermore, our LLs are still being established through the SCORE project. LLs established for a longer period and already certified might have other experiences. The ISM model resulted in this research might not apply to all LLs and NbS cases. Replicating the study in other contexts could expand our findings and improve their generalisability.

We suggest two avenues of future research to address the limitations of this study. First, in the quantitative direction, we suggest finding direct and indirect pathways through Structural Equation Modelling (SEM). For example, exploring the direct and indirect roles of financial and human resources in the co-creation process. Second, a more qualitative study could be conducted to provide a more in-depth understanding how certain combinations of enablers work in practice in specific contexts utilizing, for instance, a Qualitative Comparative Analysis (QCA).

5. Conclusions

There is a growing ambition to mainstream NbS into global agendas to achieve climate change mitigation and adaptation goals. NbS are increasingly recognized for their potential to address diverse societal challenges in a multifunctional, action-oriented, and contextualized manner, with several EU projects being implemented in the past years (Martin et al., 2021; Voskamp et al., 2021; Lupp et al., 2021). Despite the increasing attention and application of NbS, challenges related to stakeholder engagement persist (Calliari et al., 2022; Lupp et al., 2021b; Mitić-Radulović and Lalović, 2021). In this article, we intended to address the research gap in understanding which lessons can be learned from multiple participatory cases and how co-creation processes can be successfully articulated.

We identified five levels of influence among fifteen co-creation enablers, which were then categorized into four groups. The configurational set of enablers which mostly explains the enabling of co-creation is a combination of 'sharing and learning from real-life examples' and 'opening opportunities for informal inputs'. These two drivers can potentially boost the entire co-creation process, affecting all the other enablers. In addition, having a robust engagement toolbox also seems a crucial point in enhancing co-creation. Based on our ten empirical cases of LLs applying NbS to increase climate resilience in European coastal cities, we recommend that environmental managers focus their efforts on exploring these three enablers, as they seem vital to foster co-creating NbS within LLs. These promising findings add to the current body of literature, opening new pathways for research.

Our findings contribute to science, policy, and practice by bringing evidence-based insights into strategically boosting co-creation. By understanding how enablers are interlinked and can be prioritized based on their driving and dependence powers, environmental managers can better use their resources and engage with their key stakeholders more successfully.

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CRediT authorship contribution statement

Laura Quadros Aniche: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Jurian Edelenbos:** Writing – review & editing, Validation, Supervision. **Rochelle Caruso:** Writing – review & editing, Investigation. **Spela Zalokar:** Writing – review & editing, Methodology, Investigation. **Elina Makousiari:** Writing – review & editing, Investigation. **Marta Irene DeLosRíos-White:** Writing – review & editing, Investigation. **Alberto Gianoli:** Writing – review & editing, Validation, Supervision. **Elena Marie Enseñado:** Writing – review & editing, Project administration, Investigation, Funding acquisition.

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.

Data availability

Data will be made available on request.

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Appendix A. enablers for co-creating Nature-based Solutions within Living Labs from the literature

Table A presents the enablers for co-creating Nature-based Solutions within Living Labs identified in our literature review. We have used the search engines Scopus and Web of Science, searching for literature containing "nature-based solutions" or "ecosystem-based adaptation", "living lab", "urban" or "coastal", and "stakeholder" or "participation" or "co-creation" or "co-design" or "co-production". We found a total of 44 articles, which were all scanned. Out of those, 31 were selected as to fit the aim of this paper. Lastly, five additional articles were included, based on relevant citations within the reviewed papers. A preliminary list of 42 enablers was done based on this review. We have then used the 27 most cited enablers (Table A) in the discussion with the experts for their prioritization of 15 enablers within the first step of the ISM methodology, described in the article.

Table A1
Enablers for co-creating Nature-based Solutions within Living Labs from the literature.

Rank Primary data	Rank secondary data	Enabler	Literature sources
1	15	Sharing and learning from real-life examples	1; 2; 4; 8; 12; 16; 18; 19; 20; 22; 24; 32
2	24	Project planning	1; 5; 6; 9; 12; 14; 21; 22; 35
3	20	Integrating local, tacit, and expert knowledge	1; 5; 12; 16; 17; 19; 27; 28; 30; 32; 34
4	11	(Continuous) financial and human resources	5; 12; 13; 14; 15; 18; 19; 21; 23; 24; 27; 28; 30; 33; 35; 36
5	1	Interdisciplinary and cross-sectoral approach	3; 4; 5; 6; 7; 9; 11; 12; 15; 16; 17; 18; 19; 20; 21; 22; 27; 28; 30; 32; 34; 36
6	7	Context-specificity	1; 4; 5; 6; 8; 9; 12; 15; 19; 21; 22; 25; 27; 28; 30; 31; 32; 34
7	3	Engagement tools	1; 3; 5; 6; 7; 8; 9; 13; 16; 17; 18; 20; 21; 22; 26; 28; 30; 32; 34; 36
8	25	Opportunity for informal inputs	6; 7; 12; 14; 15; 18; 19; 29; 36
9	23	Tools for knowledge exchange	7; 9; 14; 20; 21; 22; 25; 28; 35
10	27	Open, effective, and consistent communication	4; 5; 6; 7; 9; 12; 19; 21; 22
11	14	Dissemination activities	7; 8; 9; 13; 14; 15; 18; 19; 21; 22; 32; 34; 35
12	18	Shared vision	1; 6; 7; 8; 12; 14; 15; 21; 22; 33; 36
13	21	Leadership and coalitions of support	12; 15; 16; 18; 21; 23; 29; 30; 33; 36
14	5	Open and inclusive process	1; 5; 8; 9; 12; 15; 16; 19; 20; 21; 25; 27; 28; 30; 31; 32; 33; 35; 36
15	4	Community ownership and empowerment	4; 5; 6; 7; 8; 9; 10; 12; 14; 15; 16; 18; 20; 22; 25; 29; 30; 32; 34; 36
16	9	Prototyping and experimenting	2; 3; 5; 6; 7; 12; 14; 15; 16; 19; 21; 29; 31; 32; 33; 35; 36
17	13	Adaptive approach and responsive feedback	5; 6; 8; 12; 13; 16; 17; 18; 20; 21; 28; 30; 32; 34
18	2	Trust, accountability, and legitimacy	2; 3; 4; 5; 6; 8; 9; 12; 14; 15; 16; 18; 20; 21; 22; 25; 28; 29; 30; 32; 33; 36
19	8	Community of interest and practice: policy-practice-society nexus	1; 2; 5; 9; 10; 12; 13; 14; 15; 18; 21; 22; 25; 28; 30; 32; 35
20	16	Stakeholder mapping, analysis, and orchestration	6; 8; 9; 10; 12; 14; 16; 18; 19; 21; 22; 36
21	26	Grassroot actors and pressure groups	14; 15; 18; 19; 22; 28; 31; 32; 36
22	17	Conflict management	1; 8; 9; 10; 12; 15; 16; 18; 19; 21; 22; 28
23	6	Co-producing knowledge and collaborative research	1; 2; 5; 7; 8; 10; 12; 16; 19; 21; 22; 27; 28; 30; 31; 32; 34; 36
24	22	Knowledge institutions	2; 7; 16; 20; 24; 28; 32; 34; 35
25	19	Building new coalitions and networks	14; 15; 16; 18; 22; 27; 29; 30; 31; 32; 34
26	12	Intermediaries, mediators, and knowledge brokers	1; 2; 3; 7; 8; 9; 12; 14; 15; 16; 18; 19; 22; 28; 32
27	10	Favourable legal conditions	1; 3; 5; 7; 9; 12; 14; 15; 16; 18; 19; 24; 28; 29; 31; 32; 33

Sources: [1] Sarabi et al. (2021); [2] Frantzeskaki et al. (2019a); [3] Wamsler et al. (2020); [4] Tiwari et al. (2022); [5] Mahmoud et al. (2021a); [6] DeLosRíos-White et al. (2020); [7] Arlati et al. (2021); [8] Lupp et al. (2021a); [9] Nunes et al. (2021); [10] Hügel and Davies (2020); [11] Rizzo et al. (2021); [12] Wickenberg et al. (2022); [13] Calliari et al. (2022); [14] Willems et al. (2020); [15] Martin et al. (2021); [16] Frantzeskaki et al. (2019b); [17] Voskamp et al. (2021); [18] Bradley et al. (2022); [19] Schmalzbauer (2018); [20] Lupp et al. (2021b); [21] Knickel et al. (2019); [22] Mitic-Radulovic and Lalovic (2021); [23] Zingraff-Hamed et al. (2019); [24] Yu et al. (2019); [25] Toxopeus et al. (2020); [26] Newton and Frantzeskaki (2021); [27] Tschersich and Kok (2022); [28] Bongarts Lebbe et al. (2021); [29] Wijesinghe and Thorn (2021); [30] Pascual et al. (2022); [31] Cousins (2021); [32] Kabisch et al. (2016); [33] Willems et al. (2022); [34] Koefoed (2019); [35] Mahmoud et al. (2021); [36] Shahani et al. (2022).

Appendix B. Reachability Matrix and Partitioning of Levels

Reachability Matrix

As we started with one RM per LL, based on their nine individual questionnaire responses, we first had to compile them into the overall SSIM. For that, we considered that a relationship between a certain pair of variables occurs if more than two thirds of the LLs have indicated to (coloured in grey in Table B1). Table B1 below summarizes the percentage of LLs that indicated an influence between each pair of enablers, which was used to develop the overall SSIM presented in the article (Table 2).

Table B 1
Percentages of the cases which indicated an influence between each pair of enablers. Percentages above 67 % (more than two thirds) are highlighted in blue and considered as occurrence of the relationship for the study.

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15
E1	100%	89%	67%	56%	89%	67%	78%	89%	100%	33%	78%	78%	22%	67%	78%
E2	56%	100%	44%	67%	33%	33%	44%	22%	11%	56%	78%	67%	44%	56%	22%
E3	56%	67%	100%	44%	89%	89%	33%	56%	78%	56%	78%	100%	22%	89%	89%
E4	22%	67%	44%	100%	22%	33%	67%	22%	33%	67%	67%	22%	44%	56%	67%
E5	56%	67%	67%	11%	100%	0%	56%	67%	78%	11%	56%	78%	67%	67%	78%
E6	67%	89%	100%	33%	22%	100%	89%	67%	78%	67%	100%	89%	67%	78%	100%
E7	56%	67%	67%	33%	89%	67%	100%	78%	78%	89%	78%	89%	56%	89%	11%
E8	56%	22%	89%	0%	100%	67%	78%	100%	22%	67%	100%	89%	0%	78%	78%
E9	56%	11%	56%	0%	78%	67%	56%	33%	100%	78%	89%	67%	33%	78%	33%
E10	11%	67%	67%	22%	44%	67%	44%	56%	78%	100%	89%	78%	67%	89%	100%
E11	44%	33%	56%	22%	100%	78%	56%	33%	67%	89%	100%	78%	56%	67%	89%
E12	33%	89%	33%	11%	67%	78%	33%	33%	33%	67%	56%	100%	67%	78%	56%
E13	11%	67%	11%	89%	33%	44%	33%	11%	22%	67%	44%	89%	100%	56%	67%
E14	56%	67%	56%	33%	78%	67%	33%	56%	67%	56%	78%	89%	56%	100%	89%
E15	33%	33%	78%	33%	22%	78%	33%	56%	0%	33%	67%	67%	67%	100%	100%

To construct the initial Reachability Matrix (RM) (Table B2), we replaced the V, A, O, X of the developed overall SSIM with binary numbers 0 and 1, considering:

– If the cell (i,j) in the SSIM is 'V': the cell (i,j) in the RM should be 1; and the corresponding cell (j,i) in the RM should be 0.
– If the cell (i,j) in the SSIM is 'X': the cell (i,j) in the RM should be 1; and the corresponding cell (j,i) in the RM should also be 1.
– If the cell (i,j) in the SSIM is 'A': the cell (i,j) in the RM should be 0; and the corresponding cell (j,i) in the RM should be 1.
– If the cell (i,j) in the SSIM is 'O': the cell (i,j) in the RM should be 0; and the corresponding cell (j,i) in the RM should also be 0.

Table B 2
Initial Reachability Matrix.

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15
E1	1	1	0	0	1	0	1	1	1	0	1	1	0	0	1
E2	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0
E3	0	0	1	0	1	1	0	0	1	0	1	1	0	1	1
E4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
E5	0	0	0	0	1	0	0	0	1	0	0	1	0	0	1
E6	0	1	1	0	0	1	1	0	1	0	1	1	0	1	1
E7	0	0	0	0	1	0	1	1	1	1	1	1	0	1	0
E8	0	0	1	0	1	0	1	1	0	0	1	1	0	1	1
E9	0	0	0	0	1	0	0	0	1	1	1	0	0	1	0
E10	0	0	0	0	0	0	0	0	1	1	1	1	0	1	1
E11	0	0	0	0	1	1	0	0	0	1	1	1	0	0	1
E12	0	1	0	0	0	1	0	0	0	0	0	1	0	1	0
E13	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0
E14	0	0	0	0	1	0	0	0	0	0	1	1	0	1	1
E15	0	0	1	0	0	1	0	0	0	0	0	0	0	1	1

Next, we applied the transitivity rule, an assumption that if A is related to B and B to C, therefore A must be related to C, so that some "0 s" were now filled with "***1****". The result is the final Reachability Matrix, which contains the driving and dependency powers of each enabler. The driving power is the total of enablers (including itself) that may be supported (influenced) by the specific enabler, while the dependence power is the number of enablers (including itself) that may support this certain enabler.

Table B 3
Final Reachability Matrix. DEP = dependence power. DRP = driving power. The number "1" indicates that the enabler in the horizontal line (i) affects the enabler in the vertical line (j) in the table. The number "0" indicates otherwise - the enabler in the horizontal line (i) does not affect the enabler in the vertical line (j) in the table. The number "*1**" (with bold, italic, and starred characters) indicates a change in the table due to the transitivity assumption.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	DRP

(*continued on next page*)

Table B 3 (*continued*)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	DRP
1	1	1	***1****	0	1	***1****	1	1	1	***1****	1	1	0	***1****	1	13
2	0	1	0	0	***1****	***1****	0	0	0	***1****	1	***1****	0	0	***1****	7
3	0	***1****	1	0	1	1	***1****	0	1	***1****	1	1	0	1	1	11
4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
5	0	***1****	***1****	0	1	***1****	0	0	1	***1****	***1****	1	0	***1****	1	10
6	0	1	1	0	***1****	1	1	***1****	1	***1****	1	1	0	1	1	12
7	0	***1****	***1****	0	1	***1****	1	1	1	1	1	1	0	1	***1****	12
8	0	***1****	1	0	1	***1****	1	1	***1****	***1****	1	1	0	1	1	12
9	0	0	0	0	1	***1****	0	0	1	1	1	***1****	0	1	***1****	8
10	0	***1****	***1****	0	***1****	***1****	0	0	1	1	1	1	0	1	1	10
11	0	***1****	***1****	0	1	1	***1****	0	***1****	1	1	1	0	***1****	1	11
12	0	1	***1****	0	***1****	1	***1****	0	***1****	0	***1****	1	0	1	***1****	10
13	0	***1****	0	1	0	***1****	0	0	0	0	0	1	1	***1****	0	6
14	0	***1****	***1****	0	1	***1****	0	0	***1****	***1****	1	1	0	1	1	10
15	0	***1****	1	0	***1****	1	***1****	0	***1****	0	***1****	***1****	0	1	1	10
DEP	1	13	11	2	13	14	8	4	12	11	13	14	1	13	13	

Partitioning of Levels

We have partitioned the Reachability Matrix into different levels. This is a process done to determine the importance level of each enabler of co-creation. Using the Final Reachability Matrix, we established for each enabler three sets:

– Reachability set: enablers that are affected by this specific enabler.
– Antecedent set: enablers that may affect this specific enabler, including itself.
– Intersection set: enablers that are common in both reachability and antecedent sets.

To establish the level of each enabler, we looked at the reachability and intersection sets. Enablers with the same reachability and intersection sets were considered as pertaining to the first level. Next, we removed these enablers from level 1 from the table and repeated the process iteratively until have classified all enablers. Five rounds of iterations were necessary and are presented in Tables B4 to B8 below. The summary of this step in shown Table B9.

Table B 4
Partitioning of levels: first iteration.

Enabler	Reachability_Set	Antecedents_Set	Intersection_Set	Level
E1	E1 E2 E3 E5 E6 E7 E8 E9 E10 E11 E12 E14 E15	E1	E1	
E2	E2 E5 E6 E10 E11 E12 E15	E1 E2 E3 E5 E6 E7 E8 E10 E11 E12 E13 E14 E15	E2 E5 E6 E10 E11 E12 E15	***1***
E3	E2 E3 E5 E6 E7 E9 E10 E11 E12 E14 E15	E1 E3 E5 E6 E7 E8 E10 E11 E12 E14 E15	E3 E5 E6 E7 E10 E11 E12 E14 E15	
E4	E4	E4 E13	E4	***1***
E5	E2 E3 E5 E6 E9 E10 E11 E12 E14 E15	E1 E2 E3 E5 E6 E7 E8 E9 E10 E11 E12 E14 E15	E2 E3 E5 E6 E9 E10 E11 E12 E14 E15	***1***
E6	E2 E3 E5 E6 E7 E8 E9 E10 E11 E12 E14 E15	E1 E2 E3 E5 E6 E7 E8 E9 E10 E11 E12 E13 E14 E15	E2 E3 E5 E6 E7 E8 E9 E10 E11 E12 E14 E15	***1***
E7	E2 E3 E5 E6 E7 E8 E9 E10 E11 E12 E14 E15	E1 E3 E6 E7 E8 E11 E12 E15	E3 E6 E7 E8 E11 E12 E15	
E8	E2 E3 E5 E6 E7 E8 E9 E10 E11 E12 E14 E15	E1 E6 E7 E8	E6 E7 E8	
E9	E5 E6 E9 E10 E11 E12 E14 E15	E1 E3 E5 E6 E7 E8 E9 E10 E11 E12 E14 E15	E5 E6 E9 E10 E11 E12 E14 E15	***1***
E10	E2 E3 E5 E6 E9 E10 E11 E12 E14 E15	E1 E2 E3 E5 E6 E7 E8 E9 E10 E11 E14	E2 E3 E5 E6 E9 E10 E11 E14	
E11	E2 E3 E5 E6 E7 E9 E10 E11 E12 E14 E15	E1 E2 E3 E5 E6 E7 E8 E9 E10 E11 E12 E14 E15	E2 E3 E5 E6 E7 E9 E10 E11 E12 E14 E15	***1***
E12	E2 E3 E5 E6 E7 E9 E11 E12 E14 E15	E1 E2 E3 E5 E6 E7 E8 E9 E10 E11 E12 E13 E14 E15	E2 E3 E5 E6 E7 E9 E11 E12 E14 E15	***1***
E13	E2 E4 E6 E12 E13 E14	E13	E13	
E14	E2 E3 E5 E6 E9 E10 E11 E12 E14 E15	E1 E3 E5 E6 E7 E8 E9 E10 E11 E12 E13 E14 E15	E3 E5 E6 E9 E10 E11 E12 E14 E15	
E15	E2 E3 E5 E6 E7 E9 E11 E12 E14 E15	E1 E2 E3 E5 E6 E7 E8 E9 E10 E11 E12 E14 E15	E2 E3 E5 E6 E7 E9 E11 E12 E14 E15	***1***

Table B 5
Partitioning of levels: second iteration.

Enabler	Reachability_Set	Antecedents_Set	Intersection_Set	Level
E1	E1 E3 E7 E8 E10 E14	E1	E1	
E3	E3 E14	E1 E3 E7 E8	E3	
E7	E3 E7 E8 E10 E14	E1 E7 E8	E7 E8	
E8	E3 E7 E8 E10 E14	E1 E7 E8	E7 E8	
E10	E10 E14	E1 E7 E8 E10	E10	
E13	E13	E13	E13	***2***
E14	E14	E1 E3 E7 E8 E10 E14	E14	***2***

Table B 6
Partitioning of levels: third iteration.

Enabler	Reachability_Set	Antecedents_Set	Intersection_Set	Level
E1	E1 E3 E7 E8 E10	E1	E1	
E3	E3	E1 E3 E7 E8	E3	***3***
E7	E3 E7 E8 E10	E1 E7 E8	E7 E8	
E8	E3 E7 E8 E10	E1 E7 E8	E7 E8	
E10	E10	E1 E7 E8 E10	E10	***3***

Table B 7
Partitioning of levels: fourth iteration.

Enabler	Reachability_Set	Antecedents_Set	Intersection_Set	Level
E1	E1 E7 E8	E1	E1	
E7	E7 E8	E1 E7 E8	E7 E8	***4***
E8	E7 E8	E1 E7 E8	E7 E8	***4***

Table B 8
Partitioning of levels: fifth iteration.

Enabler	Reachability_Set	Antecedents_Set	Intersection_Set	Level
E1	E1	E1	E1	***5***

Table B9
Levels of the enablers.

Level	Co-creation enablers
I	E2 Project planning
	E4 (Continuous) financial and human resources
	E5 Interdisciplinary and cross-sectoral approach
	E6 Context-specificity
	E9 Tools for knowledge exchange
	E11 Dissemination activities
	E12 Shared vision
	E15 Community ownership and empowerment
II	E13 Leadership and coalitions of support
	E14 Open and inclusive process
III	E3 Integrating local, tacit, and expert knowledge
	E10 Open, effective, and consistent communication
IV	E7 Engagement tools
	E8 Opportunity for informal inputs
V	E1 Sharing and learning from real-life examples

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