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Innovating Nature-based Solutions: learnings from the EU Horizon 2020 RECONECT project

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ABSTRACT

This paper proposes a specialised framework that integrates the Technology Readiness Levels (TRLs) and the Commercial Readiness Index (CRI) to assess learnings from a Horizon 2020 (H2020) project on innovation development via the selection and enhancement of supporting tools and technologies for Nature-based Solutions (NbS) implementation and evaluation. We developed and applied the methodology to scout NbS-related innovations that are at a certain TRL and had the potential for commercial exploitation, and then included tailored activities to help these solutions to reach at least CRI-1 (i.e. have the business model outlined, initial market research done, business case formulated). The tools and technologies were assessed through a lens of innovation, explication, and upscaling. As a result, novel guidelines tailored for NbS innovations were established to introduce a participatory approach in TRL and CRI evaluations to support commercial exploitation for upscaling NbS into mainstream society through market uptake of H2020 frameworks.

Key words: commercial exploitation, Commercial Readiness Index, Horizon 2020, Nature-based Solutions, Technology Readiness Levels

HIGHLIGHTS

- This paper assesses learnings from RECONECT, a Horizon 2020 project on innovations for Nature-based Solution (NbS) implementation and evaluation.
- Updated guidelines are presented to address the synergies between Technology Readiness Levels and Commercial Readiness Index for six NbS tools and technologies.
- It is concluded that without a solid business plan, including a financing plan, startups and innovations will fail.

1. INTRODUCTION

In 2015, the 2030 Agenda for Sustainable Development was adopted by the United Nations Member States (United Nation 2023a). The agenda provides a blueprint for peace and prosperity for the people and the planet. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries – developed and developing – in a global partnership. They recognise that ending poverty and other deprivations must go hand in hand with strategies that improve health and education, reduce inequality, and increase economic growth – all while tackling climate change and working to preserve oceans and forests (United Nations 2023a). The July 2023 Report provides a grim and candid outlook. In the words of António Guterres, the Secretary-General of the United Nations,

> *'Unless we act now, the 2030 Agenda will become an epitaph for a world that might have been'* (United Nations 2023b)

According to the report, the impacts of the climate crisis, the war in Ukraine, a weak global economy, and the lingering effects of COVID-19 have weakened and hindered progress towards the SDGs (United Nations 2023b). The report further warns that although a lack of progress is universal, it is the world's poorest and most vulnerable that are experiencing the worst effects of these unprecedented global challenges. It goes on to highlight the existing gaps and ultimately urges the world to redouble its efforts to combat the SDGs. It does this by emphasising the immense potential for success through political will, and the utilisation and innovation of technologies, resources, and knowledge (United Nations 2023b).

The management of hydrometeorological hazards (HMHs) is facing constantly fluctuating challenges especially in the face of a changing climate, altering their extent and impact (Clar 2019) with the balance of too much water (flooding) and too little water (drought) affecting millions of people worldwide (Kalantari *et al.* 2018). Nature-based Solutions (NbS), a recently developed concept, is gaining momentum as a form of adaption (Bouzouidja *et al.* 2021; Le Coent *et al.* 2021). They seek to maximise nature's ability to provide ecosystems services via co-benefits to help humans address issues such as climate change, biodiversity conservation, water availability and quality, hazard risk reduction, and food security (Shah *et al.* 2020; Le Coent *et al.* 2021; Kumar & Kunhamu 2022; Mashiyi *et al.* 2022). The International Union for Conservation of Nature (ICUN) defines them as *actions to protect, sustainably manage, and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits* (Shah *et al.* 2020; Langemeyer & Baró 2021; Ordóñez 2021; Kumar & Kunhamu 2022). Owing to their multi-functionality, NbS are becoming increasing popular in sustainable land-use planning and reducing vulnerability and risk to HMHs (Kumar *et al.* 2021; Langemeyer & Baró 2021; Hovis *et al.* 2022; Penny *et al.* 2023a).

A part of the programme SOCIETAL CHALLENGES – Climate action, Environment, Resource Efficiency, and Raw Materials (European Commission 2014), the RECONECT (Regenerating ECOsystems with Nature-based solutions for hydrometeorological risk rEduCTion) project aims to enhance Europe's framework on NbS for hydrometeorological risk reduction by demonstrating, referencing, upscaling, and exploiting large-scale NbS in rural and natural areas in a sustainable and financially viable way. RECONECT encompasses three spheres; water, nature, and people as dominant themes for driving NbS implementation globally and directly addresses SDG3 Good Health and Well-being, SDG6 Clean Water and Sanitation, SDG9 Industry, Innovation, and Infrastructure, SDG10 Reduced Inequalities, SDG11 Sustainable Cities and Communities, SDG13 Climate Action, SDG15 Life on Land, and SDG17 Partnerships for the Goals. The RECONECT project has partnered with a number of diverse stakeholders from different geographic characteristics, institutions/governance, and social/cultural settings across Europe and internationally. These are defined as Demonstrators and Collaborators. To achieve these goals, RECONECT has brought together a range of transdisciplinary partners from researchers, industry, consultancies, and local authorities.

The RECONECT objectives associated with this paper include: (1) identifying and enhancing key technologies and tools to support the co-evaluation of NbS, and (2) exploring and strengthening the market value of RECONECT outcomes, assessing the potential for upscaling, investigating value chains, and consolidating all lessons learnt during the project.

The aim of this work was to tie the knot between Technology Readiness Levels (TRL), Commercial Readiness Index (CRI), and business development, linking the synergies between them and when brought under a participatory approach, aiming for commercial exploitation and upscaling of NbS in society through market uptake (a key focus area within Horizon 2020 (H2020) projects). Prior to this study, nothing has been done before. TRL was adopted by the European Commission to assess research innovation (Héder 2017) via nine scales. H2020 projects interpret TRL as the path from TRL-1, for idea to market, to TRL-9, meaning a product in question is proven in its operational environment, and use this scale as a reference point for determining the development or maturity of research and its readiness for market uptake (APRE & CDTI 2022). CRI goes beyond the TRL scale and addresses the commercialisation of the said technologies by evaluating their success in the market (Héder 2017). This paper is set to demonstrate that TRL and CRI go beyond 'evaluation and monitoring' of NbS tools and models. For this, a number of objectives were set:

- Assess the benefits of a specialised framework for TRI and CRI to upscale NbS-related tools and technologies into mainstream society and business markets.
- Establish a methodology supporting NbS tools and technologies developers to engage with stakeholders and business development specialists.

- Develop a blueprint for innovation development and commercial exploitation of the results in EU-funded projects.

1.1. H2020 projects successes and failures in the area of research and innovation

Per the definition provided by the European Commission (2023), innovation is the use of new ideas, products, or methods where they have not been used before. Innovation can also be defined as the practical implementation of ideas that result in the introduction of new goods or services or improvement in offering goods or services (Schumpeter 1983). H2020 was the biggest EU research and innovation (R&I) program (EUR 80 billion over 7 years, 2014–2020) (Saletti *et al.* 2020; Marzi *et al.* 2022). It aims to ensure Europe produces world-class science, remove barriers to innovation, and facilitate collaboration between public and private sectors (Marzi *et al.* 2022). With an emphasis on excellent science, industrial leadership, and tackling social challenges, the programme was designed to drive economic growth and create jobs by coupling R&I. In the first 3 years of the programme, one-fourth of the total H2020 budget was allocated to more than 11,000 signed grants and involved world-class participants from education, research, and private sectors from over 130 countries in a range of disciplines and themes (European Commission 2017b), with stakeholders finding that the H2020 projects had a higher added value than other national or regional programmes (European Commission 2017a).

An interim evaluation conducted between 2018 and 2020 by the European Commission (2017b) assessed H2020's current progress. The positives from the H2020 projects resulted in 4,043 peer-reviewed publications, two-thirds of which were published in open-access journals and cited 78% more than the world average. Of this, one in five were based on interdisciplinary academic/private sector collaboration (twinning), with 71% of European research council projects making scientific breakthroughs; in fact, 17 Nobel Prizes received support from H2020 (European Commission 2017b). Secondly, H2020 has been able to attract and involve more small and medium-sized enterprises (SMEs), an extremely important aspect for the EU economy and necessary for achieving innovation. H2020 so far has resulted in 153 patent applications and 24 trademarks, 229 prototypes, 801 testing activities, and 81 clinical trials. Approximately 70% of the aforementioned SMEs are new to the market innovations and more than half have now reached the market (European Commission 2017b), a CRI of 3 and above.

However, although H2020 is producing world-class excellence in science, the report found that the first projects have obvious limitations. H2020 suffers from underfunding, resulting in large-scale oversubscription (success rate of 11.6%) (European Commission 2017b). There also remains an innovation gap, with the EU lagging behind breakthrough and market-creating innovation, spending too little on R&I, especially in areas of sustainable development and climate change (European Commission 2018a, 2018b). Key challenges have arisen with very few projects completed, limited data availability, time lags for R&I impacts, low involvement from civil society and the general public, and feedback from projects into policymaking. Both reports concluded that the H2020 projects focus on research and not necessarily innovation, i.e. good at making models but need further guidance. Thus, international cooperation needs to be further intensified to address the barriers to market, and to create innovations and breakthroughs, customer acceptance for full market uptake, and to ensure an appropriate balance of TRLs (European Commission 2017b 2018a, 2018b). Consequently, to prioritise R&I in the EU, the budget for H2020 projects was doubled post 2020 (European Commission 2017a), it was also stipulated that there would be full continued engagement with the UK post Brexit. H2020 has been succeeded by Horizon Europe, which seeks to deliver impactful innovation along three dimensions; Scientific, Technological/Economic, and Societal (European Commission 2022). However, the challenges remain in turning funded projects into innovations, market applications, and products.

1.2. Innovation in the field of NBS in the H2020 projects

RECONECT is connected to a number of different projects across Europe. Its two main sister projects that it runs alongside and that also came from H2020 funding are OPERANDUM (2022) and PHUSICOS (2023).

The PHUSICOS project aimed to demonstrate how NbS provide robust, sustainable, and cost-effective measures for reducing the risk of extreme weather events in rural mountain landscapes. The intention was to support the adaption of NbS technology and philosophy into mainstream climate change risk management in Rural Mountain Areas, with a primary focus on the demonstration of NbS in practical applications, looking at hazards such as landslides in particular (Strout 2020).

The project itself defines innovation as the process of creating value by applying novel solutions to meaningful problems and is not the same as an invention. An invention is instead the process of creating something entirely new (Strout 2020). Innovations that came from the PHUSICOS project included:

- The Framework Assessment Tool, for evaluating/scoring the NbS using multi-criteria decision analysis. Unlike previous tools, its scalability and adaptability meant it can be applied to different contexts and sectors with greater attention given to social and economic aspects.
- 'Living Labs' (LLs), a service innovation or co-creation process combining NbS and disaster risk reduction (DRR). LLs provide innovation by identifying stakeholder needs as well as capturing existing stakeholder knowledge. A critical reflection of LLs in PHUSICOS identified challenges related to transparency, legitimacy, durability, and equality between researchers and practitioners for co-designing procedures. To deal with these challenges, it was decided in PHUSICOS for LLs to be conducted accomplishing other national, regional, and local governance processes and ensuring that the general public was involved in or, at the very least, informed via LLs (Pauleit 2020).
- Learning Arena Innovation, an educational course to provide information on NbS for climate adaption relating to implementing NbS into public works, i.e. webinars, videos, and a serious game 'A Complex Social-Ecological Simulation on NbS'. The course was aimed at stakeholders involved in technical services, agriculture zoning, environmental management, emergency and legal services, and for private consultants and contractors.

In the OPERANDUM project, site-specific and innovative NbS were co-designed, co-developed, deployed, tested, and demonstrated with partners and local stakeholders in open-air laboratories (OALs). These OALs were natural and rural LLs that covered a wide range of hazards with different climate projections, land-use, and socio-economic characteristics, with the aim of enhancing European resilience, by reducing hydrometeorological risks in rural and natural territories, by overcoming barriers for NbS implementation (OPERANDUM 2022). Through the OALs, OPERANDUM was able to deliver tools and methods to validate NbS. This included:

- The Geospatial Information Knowledge platform, or GeoIKP, where the user can find sustainable ways to reduce the risks of hydrometeorological events. The platform also offers insights into existing successful NbS; an overview on related policies and legal frameworks; and a step-by-step plan for co-creation. The profiles it addresses include: Scientist, Business people and Investors, Policymakers, Associations, and Citizens. The platform also provides access to the NbS toolkit, which helps the user visualise and explore data using advanced mapping tools and browse NbS case studies in an interactive spatial environment (GeoIKP 2023).

However, it is unclear to what extent these innovations developed or implemented under PUSICOS and OPERANDUM H2020 funding managed to find their way to the market, or whether there is a commercial exploitation strategy to ensure market uptake of these innovations. Overall, NbS uptake is slow due to the lack of internationally recognised and comparable standards for assessing their performance, hindering the establishment over conventional grey approaches (Kumar *et al.* 2021), with their effectiveness depending on location, architecture, typology, green species, and environmental conditions as well as interrelated non-linear systems (Debele *et al.* 2019). Against that background lays the importance of developing practical methodologies that combine both the research and business mind sets, focusing on the commercial exploitation aspects of NbS innovations. This paper introduces such a methodology, through the analysis of innovations within the selection and enhancement of supporting tools/models/decision support system (DSS) for NbS implementation.

1.3. Commercial exploitation in H2020 projects

Despite the focus on R&I and the aim of commercial exploitation of the results of H2020, it lacks a commercial exploitation plan or methodologies that project implementers might follow, including the development and commercialisation of specific NbS innovations (e.g. tools). However, research has been conducted within other research themes that provide a springboard or a starting point for future technologies, identifying research gaps and funding opportunities. For example, Marzi *et al.* (2022) reviewed 56 H2020 projects dealing with electrofuel production and integration, and found that many electrofuel production technologies have not yet been fully developed. Moreover, Saletti *et al.* (2020) conducted similar research on 42 H2020 projects between 2014 and 2016 looking at R&I for smart energy systems. Saletti *et al.* (2020) established a starting point for the evaluation of future technologies, as well as highlighting research gaps and funding opportunities within future Europe R&I programmes. Whereas Gkoumas *et al.* (2022) evaluated 3381 EU-funded projects between

2007 and 2020 taking into account 867 different technologies under 45 technology themes. This paper expands the understanding of the role of funding to innovate transport and offers suggestions to further improve research funding allocation. Finally, Cronin *et al.* (2022) conducted research on 50 multi-actor H2020 projects linked to agriculture, forestry, and related sectors – using a systematic and comparative analysis called MINOS (multi-level innovation system framework). The methodology was based on semi-structured interviews with work package leads, task leaders, scientific coordinators, and country respondents for project implementations (Cronin *et al.* 2022).

The results from all these studies have found that stakeholder engagement and dissemination are a quintessential element of H2020 projects, but R&I is scarce (Cronin *et al.* 2022). Klessova *et al.* (2022) proposed an approach to assess the advancement of market-upstream innovations and technology maturity directly and objectively, through semi-constructed interviews with 49 project members. The paper presents an exploratory qualitative multi-case study of 54 innovative technologies at different maturity levels across 5 large R&I projects including 67 organisations. The findings provide the groundwork for future research of market-upstream innovation and how innovation performance within projects can be measured at early stages of the innovation process.

1.4. Integration of TRLs and CRI for innovation maturity and readiness to market

R&I monitoring tools are important to assess the current state of development so that research funding and policymaking efforts can be optimally aligned (Gkoumas *et al.* 2021). In terms of commercial exploitation for innovations, there is a big potential for H2020 projects, mainly due to the number of outputs generated from the projects. Innovation maturity and the readiness to market (Klessova *et al.* 2022) can be analysed and evaluated by the TRL and CRI scales. The TRLs were originally defined by NASA as 'a type of measurement system used to assess the maturity level of a particular technology', and are used as a reference point for many EU-funded projects. The TRLs evaluate maturity according to a scale, 'idea to market', where 1 is defined as 'basic principles are documented', and 9 is where the technology has been released and is in industrial production (Figure 1). While scientific research activities and proof of concept belong to the first few TRLs, that is TRL-1–4 (Saletti *et al.* 2020), prototyping is considered part of the developmental activities TRL-5–7, and Innovation is limited to the last two TRLs, TRL-8 and TRL-9, where technology is in its final form, works under expected operational conditions, and is approaching manufacturing or commercialisation (Saletti *et al.* 2020). However, an increased TRL does not mean a successful product, rather a TRL-9 means the product in question is only proven in its operational environment and may include some market regulations, i.e. it may or may not be properly branded, but there is purchasing power behind the product to buy the product and there isn't any apparent disruptive competition (Héder 2017). To tackle this problem, CRI was developed. There are six levels within the scale, and they go beyond the TRL scale with Level 1 CRI coinciding with TRL-1–7 and Level 2 coinciding with TRL-8 and TRL-9 (Héder 2017) (Figure 1). The CRI levels include the following: (1) Hypothetical commercial proposition, (2) Commercial trial, (3) Commercial scale up, (4) Multiple commercial applications, (5) Market competition driving widespread deployment, and (6) 'Bankable' grade asset class.

EU projects have yet to combine the TRLs and CRI levels, which is where motivation for this study was derived. The novelty lies in the fact that we have developed and applied the idea of TRL guidelines combining them with CRI and then tailored the scores for the context of NbS. TRLs are the reference points used in many EU projects; however, as mentioned previously, many struggled to translate the results into impact or marketable innovations. By integrating both TRLs and CRI, we have in essence incorporated an evaluation of commercialisation of NbS innovations and provide simplified guidelines to help users apply correct TRL and CRI levels.

2. METHODOLOGY

2.1. Development of a specialised TRL and CRI framework for NbS

It was deemed essential that a specialised guideline be created to evaluate NbS tools/technologies within the RECONECT project with regard to innovation enhancement/readiness for market in a simple explanatory manner through criterion applicable to TRLs and CRIs (Figure 2). Therefore, building on the scales defined by Héder (2017) and NASA (2021), TRL and CRI scores were integrated into a framework and adapted for the NbS context. In this study, due to the prototype nature of the tools/technologies chosen, we only considered up to TRL-9 and CRI-2, as it was unlikely any would reach a CRI-3–6 (Commercial Deployment). However,

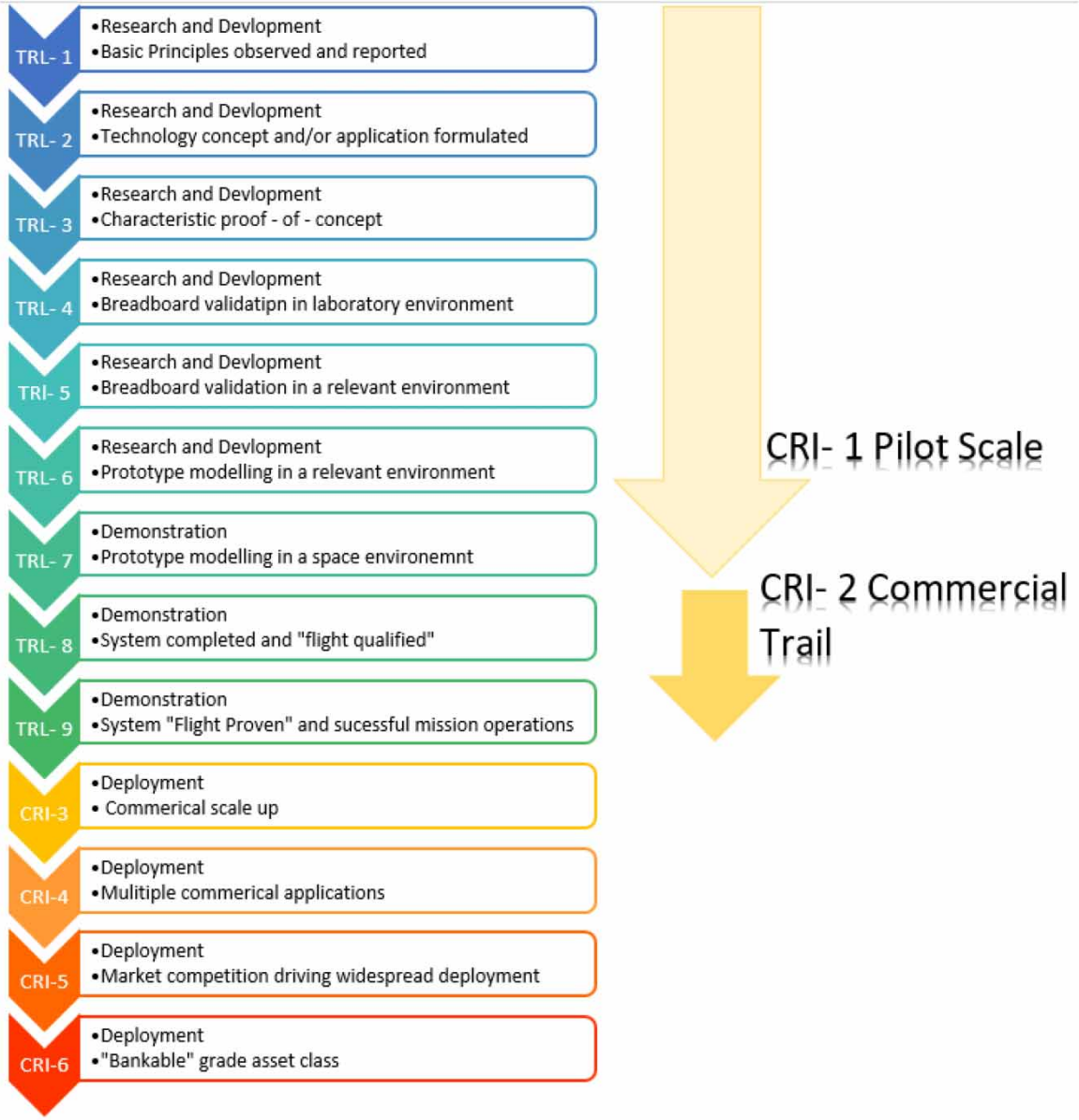

Figure 1 | Comparison of TRL and CRI scales (adapted from Héder (2017) and NASA(2021)).

the guidelines produced in this study cover the journey from TRL-1 to CRI-6, so can be used and adapted for other applications.

The exploitation dealt within the RECONECT project is the utilisation of results to support upscaling the use of NbS for hydrometeorological risk reduction (UFZ 2021). The results represent outputs generated by RECONECT that can be used to create impact. Commercial exploitation in this context refers to using these results to reach the industry (European Commission and European Research Executive Agency 2023). Specifically, we aimed at identifying innovative ideas generated within the RECONECT project, which could be in the form of software, prototype, service, tool, model, or DSS whose developers are aiming to create a startup and enter the commercial market.

The concepts of TRL and CRI integrated into a specialised framework are used in this methodology to help inform the level of development along the growth journey, from the research and development stage up to being tested, quality controlled, and available in the market. While this methodology is intended as an approach to follow for any potential startups from RECONECT or other Horizon Europe projects, it has been developed in coordination with specific RECONECT partners (innovators/potential startups) and the process documented along the way is presented in the format of a blueprint in the subsequent parts of this methodology.

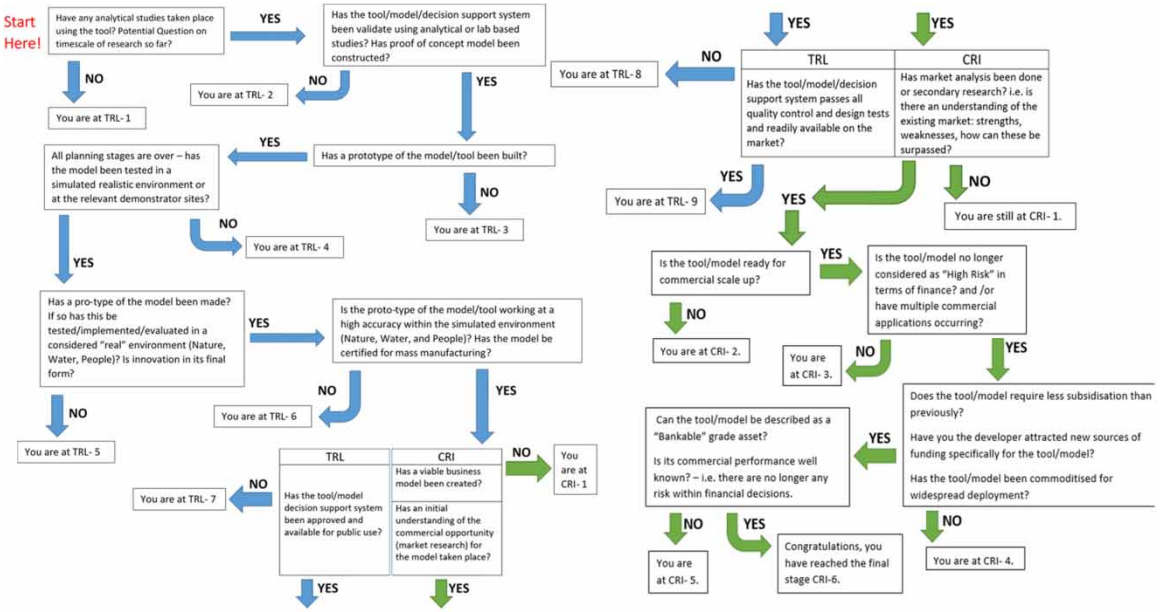

Figure 2 | Specialised TRL and CRI framework to evaluate RECONECT tools/technologies.

2.2. Roadmap for the commercial exploitation of Horizon Europe projects

The methodology followed the roadmap set to scout and develop innovations in the area of NbS, and after a multi-criteria assessment and screening, to lead the most promising and novel solutions to the path for commercial exploitation (see Table 1). As a result, we were able to identify innovations with the highest potential to become startups that could, in time, enter the market and succeed as a business, out of the pool of technologies, models, tools, DSSs being developed in the area of NbS. The roadmap details the activities related to the scouting of the innovations externally and internally, deeper investigation of these innovations, assessment of their TRLs and CRI levels, filtering of the innovations using these screening criteria, development of tailored collaborative workshops along the way and application of certain exercises, tools, and methods that have helped to reach the aim. Following the roadmap we were able to narrow down to six solutions and help them establish and progress their business models and timelines for commercial development. Our approach is replicable for other innovators and could be further applied to other Horizon Europe projects.

2.3. Scouting of innovations within RECONECT project

We, the partners at RECONECT project, focused on innovation in the field of NbS by employing a collaborative approach and pragmatic lens, and have started with internal and external scouting of innovations. Narrowing down from external to internal scouting, we applied several methodologies and exercises.

First, we adopted the Lead User Method (Lüthje & Herstatt 2004; Sørup *et al.* 2019) to outline global innovations addressing hydrometeorological risk (Manojlovic *et al.* 2021). The Lead User Method is a step-by-step process to identify user innovators and find ways to upscale the most valuable innovations and to make them generally available for those in need. These innovations are usually highly frugal, often very sustainable solutions, oriented towards local communities and local problems, with potential for scaling or adaptation to other areas. We adapted this bottom-up innovation process to detect Lead User-created NbS and evaluate their effectiveness (Sørup *et al.* 2019). Despite many existing platforms that contain both knowledge and practical relevance to existing NbS projects, it is still difficult to identify cases that show and document how NBS may benefit nature and people. The Lead User Method tackles this problem since it enables finding tested and proven Lead User innovations related to NbS, developed by the people themselves while facing hydrometeorological risks (Manojlovic *et al.* 2021).

Second, a desktop research of multiple RECONECT deliverables and interviews with representatives from demonstrator sites with large-scale NbS were conducted (RAMBOLL 2023a, 2023b, 2023c), followed by two surveys sent to the RECONECT consortium partners and a workshop, to scout for technologies, tools, models and DSSs either applied or being developed within RECONECT consortium, that are novel to the field of NbS. Third,

Table 1 | The methodology for commercial exploitation of the results using RECONECT example with the focus on innovation in the field of NbS

Step	Scouting of innovations internally and externally	First screening: technology maturity evaluation	Second screening: commercial exploitation potential	Business model-oriented consulting sessions with selected tool/technology developers	Business development workshop with selected tool/technology developers
Objectives	- Explore innovation landscape in the field of NbS; - Define how we work with innovation in RECONECT; - Define innovation types in the field of NbS; - List and categorise innovations within RECONECT; - Assess their viability, feasibility, desirability; - Screen for novelty and impact.	- Select tools, models, and DSSs for NbS implementation; - Define the innovation potential based on the needs of the end-users; - Establish current TRL; - Explore commercial exploitation potential.	- Assess the tools, models, and DSSs to funnel down to the most progressed tools; - Clarify the TRL and establish their CRI using specialised TRL and CRI framework.	- Develop the business models for each of the selected solutions, using the BMC as a framework; - Identify the areas in the business model that require expert help and further development.	- Evaluate the business cases of tools, models, and DSSs for NbS implementation developed in RECONECT; - Receive the expert feedback and set the milestones for further development; - Assess the potential for further development as RECONECT spinoff.
Outputs	A pool of conceptually screened technologies and solutions in the field of NbS	A list of tools, models, and DSSs in the field of NbS with brief one-page descriptions	A shortlist of tools, models, and DSSs in the field of NbS that have reached TRL6 with detailed one-page descriptions	First drafts of business models for selected tools/technologies	Evaluated business models of selected tools/technologies and set 1-year milestones for further development
Methods and exercises used	- Lead User Method; - Analysis of RECONECT deliverables; - Interviews with RECONECT large-scale NbS demonstrator sites; - Surveys; - Framing the innovation types in the field of NbS; - Importance vs. knowledge assumption	- Feasibility, desirability, and viability evaluation exercise; - TRL evaluation; - Workshop.	- Evaluation according to specialised TRL and CRI framework; - Interviews with tool/technology developers within RECONECT.	- BMC; - Individual sessions with tool/technology developers within RECONECT.	- BMC; - Milestone mapping; - Workshop.

(*Continued.*)

Table 1 | Continued

Step	Scouting of innovations internally and externally	First screening: technology maturity evaluation	Second screening: commercial exploitation potential	Business model-oriented consulting sessions with selected tool/technology developers	Business development workshop with selected tool/technology developers
	mapping exercise; - Feasibility, desirability, and viability evaluation exercise; - Impact vs. novelty exploitation mapping exercise; - Workshops.				
Stakeholders involved	- Tool/technology developers in the area of NbS: - within RECONECT consortium; - lead users, not associated with RECONECT; - RECONECT consortium partners.	RECONECT consortium partners	- Tool/technology developers within RECONECT consortium; - RECONECT consortium partners as technology scouts.	- Selected tool/technology developers; - Experts in business development and innovation within RECONECT consortium.	- Selected tool/technology developers; - External experts covering various relevant areas, such as business models, marketing strategies and customer relationships, design, research and development, partnerships, monetisation of data, financials, and risk.

we framed the scouted solutions by defining various types of innovations in the field of NbS via the workshops at the RECONECT General Assembly Meetings. We conducted multiple exercises to conceptually screen the scouted and categorised solutions. The importance vs. knowledge assumption mapping exercise aimed at evaluating the solutions on their importance and how well known they are in the field, revealing whether we should defer, plan, generate, or evaluate each of them. Feasibility, desirability, and viability evaluation exercises focused on key evaluation criteria, as follows:

(1) Feasibility, i.e. is it technically feasible and does it build upon RECONECT's operational strengths?
(2) Desirability, i.e. does it fit the market demand, does it fulfil the needs of people/society, and does it solve the right pain point?
(3) Availability, i.e. is it financially viable and does it contribute to long-term growth? The impact vs. novelty exploitation mapping exercise helped to identify the solutions that are novel and have a potential to make a great impact.

2.4. Screening the solutions for technology maturity and commercial exploitation potential

Aiming to narrow down to novel tools, models, and DSSs for NbS implementation, either applied or being developed within RECONECT consortium, that are technologically mature and have commercial exploitation potential, we applied two screening steps.

The first screening was specifically tailored to evaluate technology maturity and involved desk research and workshop with the RECONECT consortium. From the comprehensive list of tools, models, and DSSs, we

funnelled down the solutions to those considered feasible, viable, and desirable. We then established current TRLs and thus assessed a long list of solutions to narrow down to the most progressed tools. The TRL of an innovation is an important indicator of the maturity of a technology, and acts as a key reference point for this methodology, with TRL-1–4 identifying solutions still in the scientific research stage, TRL-5–7 for those in the prototyping stage, and TRL-8 and TRL-9 being innovations limited to the last two levels before commercialisation. By developing a good understanding of each solution, an informed screening can take place. In our case, the tool and technology developers were included to create one-page descriptions representing each solution. Using those, the RECONECT consortium partners were included in the exploration of their commercial exploitation potential. With the aim to identify if the selected solutions can be commercially exploitable, the partners brainstormed the following questions: (1) Does it hold a commercial opportunity? How great do you think that opportunity is? (2) Is the technology ready for commercial exploitation? If not, how would you improve the TRL? (3) How would you go about commercialisation? (4) Does TRL improvement or commercialisation require substantial investment? (5) Are there any improvements you would make? and (6) Who is the customer and market?

Once a clear understanding of the solutions was established, the specialised TRL and CRI framework was used in the second screening aimed at creating a shortlist of tools, models, and DSSs in the field of NbS that have reached TRL-6 and have commercial exploitation potential. As the project progressed, the TRL and CRI were established via the interviews with tool and technology developers. Those with TRL-6 and higher were shortlisted, so that focus could be targeted towards those closer to being ready to launch to the market from here forwards.

This round further scrutinised each innovation, running them through a multi-criteria analysis, assessing them for their commercial exploitation potential and suitability for progression by answering the following questions: (1) What differentiates this from competitors? (2) Is it appropriate for commercialisation (i.e. to leave the research environment)? (3) Is there clear value? Where is the value? (4) Is this ready to be trialled? (5) Is this directly related to RECONECT? (6) Could this become a standalone offering (i.e. independent of universities or other existing platforms already in the market)? and (7) Is this already a proprietary software?

The screening process resulted in six solutions being shortlisted. They were found to be the most developed and suitable innovations to progress towards the next development stage for their commercial exploitation.

2.5. Business model development

In the RECONECT project, the aim was to further develop existing prototypes, test them, and interact with end-users to further specify the usability as well as find a commercial opportunity and define a business case. Through intensive interview sessions with the developers of shortlisted solutions, business models were drafted for each of these innovations. The Business Model Canvas (BMC) by Osterwalder *et al.* (2005) was chosen as a tool and adapted for RECONECT (due to innovations developed in the field of NbS) to guide the developers by asking them questions related to value proposition, customer segments, key activities, key resources, partners, customer relationships, channels, cost structure, and revenue streams. This exercise also identified the areas in the business models that require expert help and further development.

As a final step, we organised the workshop with external experts covering various relevant areas, such as business models, marketing strategies and customer relationships, design, research and development, partnerships, monetisation of data, financials, and risk. To replicate the innovation incubation in the workshop format, technology and tool developers had an opportunity to present and have a one-to-one discussion about their business models with the different experts. This resulted in a clearer idea of the gaps, opportunities, and inspiration to follow-up on some clear forward steps on a mapped timeline for each solution, set by the technology or tool developers. The overall goal for the workshop was to further evaluate and develop business plans for the technology and tool developers and help them plan steps towards reaching the market on a short- and long-term basis through adding milestones to a timeline, with the aim of exploiting innovations and creating startups. Most importantly, we were able to assess the potential for further development of the solution as a RECONECT spinoff, which was based on the advancement regarding business model development and the feedback from the external business development consultants.

Ultimately, this process outlined in Table 1 led to the development of the methodology that (1) covers the process of conceptualisation and innovation, (2) creates an idea/technology, (3) helps business model creation and financial planning, and (4) outlines key actions for development and future timeline planning.

3. RESULTS

3.1. Development/progression of innovations within RECONECT

There is an increasing need within research to explore the use of sensors, regulators, telemetry, and supervisory control and data acquisition systems for efficient and effective operation and real-time control of NbS (Ruangpan *et al.* 2020). The number of studies that combine smart technologies within water system analysis is growing, and collectively/primitively these are known under a new umbrella term 'Smart NbS' (Ruangpan *et al.* 2020, 2023). The term covers the idea of how tools/technologies can be used in implementing and improving the capacity of NbS by reducing the HMHs, i.e. flood reduction using smart systems like Real-Time Control (Ruangpan *et al.* 2023). Ruangpan *et al.* (2020) went onto arguing that more needs to be done in the development and assessment of tools/technologies to provide more active and integrated operation solutions for NbS and to ultimately facilitate future research.

The six shortlisted NbS innovations developed within the RECONECT project included Argos, eDNA, Measure Section Tool, Water Detective, QuantiAmenity, and TeleControlNet (Appendix). Each of these innovations is arguably a 'Smart Nbs' in its own merit. They are all strongly linked to at least one of the three spheres (water, nature, and people), while providing a form of or combination of planning, implementation, monitoring, and evaluation via the visualisation of spatial, biodiversity, and socio-economic factors through forecasting, observations, and sensor data.

The development of TRL and CRI scores during the project duration of the selected innovations is portrayed in the Figure 3. Even though the solutions met the criteria of having reached at least the TRL-6, the tailored activities oriented towards commercial exploitation have helped them to establish CRI-1 and CRI-2 during the course of the project.

3.1.1. Argos

During the RECONECT project, Argos was prepared to ingest NbS-related data relating to the three pillars (water, people, and nature). The model before RECONECT was at TRL-5 and can be used to provide information, warnings, and management for different weather-induced hazards: fires, flooding, and drought. The tool is used for planning, monitoring, and evaluation of NbS. The ambition within the RECONECT project was to expand its capabilities for river catchment management from a more holistic point of view (incorporating and visualising information besides forecasts and sensors data) and achieve TRL-8 and TRL-9. However, this was not achieved although it is available to use via the RECONECT website (see the Appendix) and the prototype is working at a high accuracy in the operational environment. The challenges include the following: identifying the number of customers/partners using the platform, a lack of funding and feedback, and nor has commercial/market analysis taken place. Currently, the tool is between a TRL-6 and 7, with a CRI-1.

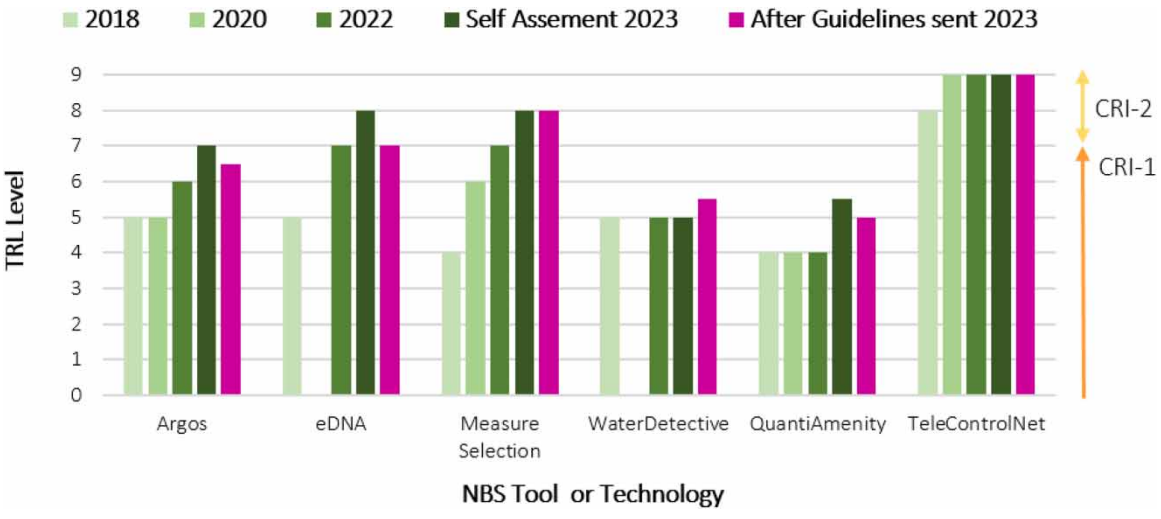

Figure 3 | Development of TRL and CRI scores for the innovations within RECONECT.

3.1.2. eDNA

Within the RECONECT project, eDNA has been used to monitor the presence/absence of the protected species Great Crested Newt in the case study area of Aarhus. eDNA sampling consists of taking water samples in the most strategic places, namely, where the species is most likely to occur. The tool before RECONECT was working at a TRL-5 with the initial target at TRL-7. Market research for the tool was conducted in France in 2019, consequently this brought to light that there was a lack in the quantification assessment in general. Therefore, it was assessed that the TRL of the technology could be improved by finding out whether the population size of one given species in a site could be quantified. Since then, the tool has been used by a small number of clients and has demonstrated that it works for individual species detection and detects the presence of the species better than with the traditional monitoring methods. However, even though eDNA is unique to the market, and saves times and labour compared with traditional methods, challenges still remain, with uncertainties around how many clients would be willing to pay for the service, and the fact that the quantification methodology needs validating. Consequently, a greater focus on market research, establishing/expanding partners and customer engagement, and the generation of a business model is needed. In this way, eDNA reached TRL-7 and a CRI-1 (Figure 3). More information about eDNA can be found in the Appendix.

3.3.3. Measure selection tool

Used for NbS planning, the measure selection tool is an online portal that provides an extensive list of NbS measures, for flooding, drought, storms, and landslides. Originally in an Excel format, it has now, through the RECONECT project, been made into an interface with graphics. The above has been used with collaborators, demonstrators, and training on NbS in Thailand. The starting TRL for the tool was TRL-4 and the target was TRL-8. Via the RECONECT website the tool is available online for public use. Though the tool is no longer in its pilot scale, it is unclear how many users are accessing the tool, hence it has reached a CRI-2 'Small-scale' commercial trial stage and its target TRL-8. However, to date neither has any market research been conducted (willingness to pay), nor any market strategy been developed. If basic market research is done, on how the model could be promoted outside of RECONECT, then the tool would reach and overpass RECONECT aims of a TRL-9 and CRI-3 commercial-scale use.

3.1.4. QuantiAmenity

This tool enables the quantification of NbS amenity values based on socio-economic data, such as recreation in a monetary manner, and can be used for planning for flooding, drought, storms, and pollution. The starting TRL was 4 and the proposed aim was between TRLs-7–9. During RECONECT's lifetime, the TRL has remained on Level 4 from 2018 to 2022 increasing to a TRL-5 and CRI-1 between 2022 and 2023 as the prototype (Python script) is only used by the Technical University of Denmark and has no user interface (Figure 3). Nevertheless, although QuantiAmenity will not be driven further than a TRL-6 within RECONECT's lifetime, if a commercial partner picked the tool up for commercialisation, it could be developed further.

3.1.5. TeleControlNet

This is the data store for all demonstrator sites within the RECONECT project covering hazards including flooding, drought, storms, extreme temperature, fire, landslide, groundwater recharge, and pollution and this can be used for planning, implementation, monitoring, and evaluation. The starting had aTRL-8, and the aim was to achieve a TRL-9 at the end of the project. During RECONECT improvements to TelControlNet were made; with new data inputs, specific reports, process overviews for NbS demonstrator sites and ongoing secondary data exchange with Argos and WaterDetective created. It is now a software as a service, with 350 customers using it daily, with updates occurring to its user interface. Subsequently, a TRL-9 and CRI-2 (commercial trial) were achieved, although it is anticipated that it will soon reach a CRI-3 (commercial scale up) (Figure 3). More information can be found in the Appendix.

3.1.6. WaterDetective

WaterDetective was an app developed for facilitating the monitoring and gathering of information from the general public about the success of NbS in their area. The aim was to increase the starting of TRL-5 to TRL-7, unfortunately it remains between TRL-5 and TRL-6 (Figure 3). The key obstacles within the process of RECONECT include that crowdsourcing requires effort from the general public. In 2019, market research found that there was a very low percentage of people willing to install the app on their smartphones, and a medium interest

to participate. An additional drawback is that the quality of the reports can be limited and the risk of potential misuse is high as the application is open and it is freely available to download. Currently, in the prototype phase (early demonstration) within RECONECT, the next steps for the app are to trail micro-payment/awards to hopefully get more of the general public using the app. This is due to occur within 2024. Another objective for the app is to integrate with TeleControlNet to help fine-tune and tailor the app according to user feedback, a date for this has not been set.

4. DISCUSSION

4.1. Development of a specialised TRL and CRI framework for NbS

Studies highlighted the importance of the inclusion of stakeholders and workshop engagement within research (Penny *et al.* 2023b), with stakeholder contributions adding additional value to research outputs. This is a powerful concept and one of growing interest to academics, governments, and policymakers, especially when considering and combining environmental problems, such as HMH, with citizen science (Shivakoti *et al.* 2019; Anshuka *et al.* 2021; Rahimi-Feyzabad *et al.* 2021, 2022; Harrison *et al.* 2022). The importance of stakeholder engagement was also shown in our blueprint (see Table 1), where the number of stakeholders involved the first time was large, then decreased over the screening process, and then increased again during the business development workshop. The methodological Section 2.1 contains the output from initial interviews with innovators and concurred with findings from Klessova *et al.* (2022) who proposed that a refinement of the TRL scale was needed as well as the scores to reflect the different domains the technologies/projects were concerned with. Gkoumas *et al.* (2021, 2022) also agreed, arguing that TRLs for evaluating innovations have been heavily criticised as they focus on the availability of a technology but not other aspects, i.e. market maturity or uptake.

From primarily conversations it became clear that TRL/CRI when applied to NbS tools/technologies were too complicated or poorly understood, and were not being applied correctly or were being overestimated (Figure 3). Subsequently, it was deemed essential that a novel specialised guideline (Figure 2) was created to help evaluate NbS tool/technologies within the RECONECT project to help explain innovation enhancement/readiness for market through a criterion applicable to TRLs and CRIs. After guidance was sent out, the TRLs were revised, and many dropped a level (Figure 3). This highlights the fact that although TRLs remain a consolidated way of assessing technology innovations, especially when exploiting synergies between research programmes (Gkoumas *et al.* 2022), an understanding of and appropriate guidance for TRI and CRI are needed. For example at the beginning of development, critical questioning is vital.

4.2. Outputs/recommendations for policymakers and practitioners

The workshop highlighted that innovation pathways for the tools/technologies within RECONECT underwent a steep learning curve, as seen by the TRLs. From the BMC it became clear that it is important from the onset of the tool/technologies development that some key questions need to be asked.

The RECONECT project's innovation journey has been a significant learning experience for all partners involved. Successful innovation requires a collaborative mindset and proactive co-creation of commercial strategies for spinoffs/startups. The ultimate goal is to upscale, mainstream, and replicate NbS in Europe and beyond. Drawing from this experience, we offer the following recommendations for the successful development and exploitation of innovative ideas:

- Define Your Purpose Early: Clearly articulate why your innovation is needed in the market. Conduct thorough market research to understand the competitive landscape and identify similar offerings.
- Structured Business Planning: Utilise frameworks like the BMC to structure your business plan. Identify strengths, weaknesses, and opportunities. Develop a revenue-generating value proposition that sets your solution apart from the competition.
- Solid Financial Planning: Ensure a thorough exploration and solidity of your financial plan. RECONECT Deliverable D5.7 (RAMBOLL 2023a) offers insights into addressing potential financing gaps. Develop a realistic value-based pricing strategy and consider segmentation per customer type.
- Market Awareness: Understand your market and competitors to identify opportunities and areas where your innovation can offer unique value.
- Client Understanding: Each customer segment is unique, spend time listening to clients, understanding their problems, and tailoring solutions to fit.

- Adaptive Product Development: Maintain a vision for your product but be ready to revise it based on market and customer feedback.
- Collaboration and Networking: Seek inspiration and ideas from within or outside your organisation. Leverage connections with experts in your field, startup creation, or market area.
- Utilise Expertise: No one is an expert in everything; tap into the skills, experience, and expertise of others.
- Set Realistic Key Performance Indicators (KPIs): Establish informed KPIs to stay on track and maintain focus during development. Regularly revisit and adjust them as needed.
- Realistic Timescales: Acknowledge that entering the market can take years for a startup. Allow for realistic development timelines.

These recommendations aim to guide the successful evolution of innovative ideas into thriving startups, emphasising strategic planning, market awareness, and adaptability (RAMBOLL 2023b, 2023c).

4.3. Limitations and future development

It is important to note some improvement that can be made to the study. Due to the aims of the project, the tools/technology chosen were working towards developing a TRL-9 CRI-2 (commercial trial), but many did not reach this and currently sit between a TRL-6/7 and CRI-1. Future research might include the scaling up of activities to conduct activities or interactions with tool developers in local incubators to help reach CRI-3–6 – 'The Deployment stage' (Figure 1). Secondly, within the project, critical questioning should have taken place earlier on, occurring within the initial stages of tool development. Not at a TRL-5 or above, so that gaps and weaknesses or strengths and potential revenue sources could be identified early on during innovation not during the last financial year of the project. Nevertheless, a key difference within RECONECT is that it is an interdisciplinary project where tool/technology owners were researchers/academics not innovators; therefore, a market was needed to be found for the idea, not vice visa, i.e. there was not an obvious gap/call for the tool or technology, but rather a technology/idea had been developed and now needed to fit to the market.

5. CONCLUSION

TRLs were originally created by NASA and thus meant for technology development, not commercial exploitation. Having used TRLs as a reference point in RECONECT, we observed the TRL progression of six tool/technologies, and although they did reach certain TRL levels, many had not advanced in terms of their potential commercial exploitation (CRI level, Figures 1 and 2). In comparison with other EU projects with a focus on NbS, we were able to bring in commercial exploitation/expertise because we have focused on six technologies/tools that are NbS related, not on developing a large-scale NbS itself. Hence, we scouted and worked with the solutions, which enable the future upscaling of smart NbS.

To conclude, without a solid business plan, including a financing plan, startups often fail. In this paper, we pioneered the application of combining TRL and CRI to outline the path of six tools/technologies for NbS implementations via the following steps: innovation exploration, technology development, business model creation, and future timeline planning. By using tools/technologies as an example, we have produced novel guidelines that help address and combine the synergies, and ultimately tie the knot between TRLs and CRIs to force an evaluation of commercialisation of innovations. With a participatory approach focus (key area in H2020 projects), we demonstrated that TRLs and CRIs go beyond 'evaluation and monitoring' of NbS tools and instead set the background for a dedicated assessment of commercial exploitation under the overarching goal of upscaling NbS into mainstream society. The six tools/technologies developed within will be used outside of the RECONECT project lifetime and carry on their CRI journey towards deployment. Thus, improvements will not end with the project's timeline, rather the tools/technologies can be expanded and upscaled for wider adaptions and become true 'Smart NbS'. Although this study's methodology focuses on the RECONECT project, the specialised TRL and CRI framework is a commercial roadmap that can be applied and adapted to wider projects/applications. By integrating both TRLs and CRIs, we have in essence forced an evaluation of commercialisation of NbS innovations and provided simplified guidelines to help users apply correct TRL and CRI levels.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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