TRANSDISCIPLINARY RESEARCH FOR SUSTAINABLE DEVELOPMENT: DIVERSE AND BEST-PRACTICE AT EUROPEAN TECHNICAL UNIVERSITIES

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Abstract: As societal challenges grow, so does the role of universities in finding social and technological solutions. Technical universities are prominent in educating future innovators and developing desired technological and social change. This paper seeks to identify commonalities and better understand differences to develop strategies for mutual support and exchange of best practices. The methodological approach focuses on three questions concerning 1) the common understanding of transdisciplinary, 2) the diversity of transdisciplinary approaches to sustainable development, and 3) the different institutional structures that enable and promote transdisciplinary approaches to sustainability. The qualitative exploratory research suggests that a higher level of societal engagement in scientific research positively impacts societal transformation towards sustainability. This research is also a first step towards making transdisciplinary research at technical universities more visible and transparent to provide better support and create a mutual learning environment for discussing and continuously developing strategies for organizational change.

Keywords: transdisciplinary, societal impact, levels of engagement, sustainable development.

JEL Classification: I23, I25.

1 Introduction

The pressing challenges of the climate and energy crises, growing poverty and inequality all call for a comprehensive re-evaluation of people's lifestyles and a collective commitment of private and public organizations to develop research modes to promote greater sustainability (Gibbons, et al., 1994; Hessels and van Lente, 2007). This imperative is also reflected in research and innovation strategies at various levels, such as the European, national, and regional levels, where the focus shifts to the actual (and measurable) impact of research and innovation activities responding to the most pressing grand societal challenges. For universities, especially large technical universities, this implies a 'call to responsibility', strengthening their role as creators and enablers of integrated knowledge and innovations capable of responding to societal needs and developing sustainable problem solutions. This requires fostering the universities' role as places of experimentation and learning, engaging, and collaborating with non-academic actors (from society, policy, and business) and beyond the laboratory to co-produce new knowledge from and about different social spheres in innovation processes. For this reason, universities are addressing sustainability through their primary missions of education, research, and innovation, and – since more recently about the third mission – through transdisciplinary as a research mode.

In 2019, seven European universities of technology allied to discuss, analyze and collaborate on such emerging approaches and develop structures for institutionalizing knowledge exchange between science and society.

The ENHANCE Alliance initially comprised seven European universities of technology and expanded to ten members in 2022. The Alliance brings together a wealth of experience in cross-sector collaboration on challenges of significant industrial and societal relevance. However, there are differences in the methods, strategies and structures used by universities and between institutions in different sectors when working towards shared objectives. The UN Sustainable Development Goals (SDGs), the upcoming Horizon Europe missions and the need for digital and green transitions necessitate universities to forge closer partnerships with the public sector, governments, citizens and the private sector. Through these collaborations, common responses can be developed to transform our research culture by shifting towards responsibility, sustainability and impact. Strategic change is, therefore, needed at multiple levels in organizations' mission, strategy and governance structures, using a systemic logic: the common goal of the ENHANCE Alliance will be not to think in silos between areas but to embrace all three dimensions together.

The ENHANCE Alliance seeks to achieve this goal through the Horizon 2020 project ENHANCERIA. Focus area 1 is dedicated to exploring sustainable development through transdisciplinary research as a research mode, which addresses transdisciplinarity as a policy and practice. Therefore, this endeavor involves an in-depth analysis of ENHANCE universities' different approaches from two perspectives: addressing sustainability regarding models, structures and strategies and promoting transdisciplinary as well as projects and practices to conduct transdisciplinary research. ENHANCERIA aims to strengthen the research and innovation aspects of ENHANCE by creating a transformative agenda highlighting universities' role as facilitators and promoters of sustainable development through an institutionalized knowledge exchange between science and society. In order to develop joint action plans and create synergies among the ENHANCE partners, it is important to identify which practices are most relevant and successful and which actions contribute to sustainable impact, reflect institutional culture, and could potentially be rolled out across the Alliance. It promotes understanding and support for transdisciplinary approaches as a research mode and develops structures for institutionalizing knowledge exchange between science and society. The research faces the following conditions: first, there is still a research gap on the institutionalization of transdisciplinarity for sustainable development (Vienna Baptista and Rojas-Castro, 2020; Ahrend and Podann, 2021; Vienna Baptista and Thomas Klein, 2022), and second, in the Alliance, there are very different perspectives on the definition and implementation of transdisciplinary research and transdisciplinarity as a research mode for sustainable development. Beyond different understandings of how transdisciplinarity is defined, it also depends on the technical university's environment – institutional structures, funding programmers, strategic directions or organizational networks. These conditions determine the extent to which sustainable development can be shaped in collaboration between science and society. The levels of engagement and the social impact are meaningful indicators of this. Transdisciplinary research is a vital principle of this objective as it increases societal relevance by involving different stakeholders directly or indirectly in the research process from defining research questions and objectives to participating in the research process and discussing its results. Evaluating the research process and its results is integral to transdisciplinary research. The outcome of this analysis provides a deeper understanding of the subject matter and includes preparatory measurements for developing a platform for transdisciplinary research.

This article examines the transdisciplinary initiatives undertaken by the universities within the ENHANCE Alliance. Facing the variety of perspectives and very different ENHANCE universities' experiences with transdisciplinary research towards sustainability, the aim is to provide a shared understanding of transdisciplinarity as a research mode at these universities. Fostering the role of universities as drivers for sustainable development also forms a common basis for developing a transformation agenda: to reveal common aspects of the ENHANCE universities' profiles

and to lead to an understanding of diversity and providing synergies. Specifically, it explores the definition and implementation of transdisciplinarity, the universities' strategic positions and governance structures, and their contributions to developing this transformative agenda. Given the considerable diversity in transdisciplinary approaches, the ENHANCE Alliance emphasizes the societal impact of these initiatives and the level of engagement of various stakeholders. Understanding how universities serve as knowledge exchange platforms with society and facilitate circular knowledge transfer is crucial. It is also essential to assess the extent to which different institutes promote transdisciplinary approaches and how the organizational structures of universities influence the performance of these initiatives. This article addresses these issues by focusing on the experiences of the ENHANCE universities. It highlights the common understanding of transdisciplinarity both conceptually and in practice, the diversity of transdisciplinary approaches to sustainable development in terms of levels of engagement, and the associated differences in societal impact in the context of fostering transdisciplinary approaches to sustainability at ENHANCE universities.

This article aims to improve our understanding of transdisciplinary research within the ENHANCE Alliance and to highlight the similarities and differences between the approaches of the universities in order to provide future synergies and to understand the challenges and barriers by implementing transdisciplinarity as a research mode. Ultimately, this analysis will advance collective knowledge and practice around transdisciplinarity and sustainability, forming a basis for developing a transformation agenda towards sustainable development in the ENHANCE Alliance.

2 State of the art

The complex and pressing challenges of societal transformation require integrative research and innovative solutions, as outlined in the United Nations 2030 Agenda for Sustainable Development (2015). Scholarly works characterize the concept of sustainability as a ‘wicked problem’ (Harris, et al., 2010). Such problems are based on social interactions that must be addressed collectively due to their numerous interdependencies and the absence of a clear-cut solution. It is essential to simultaneously address real-world limitations through constructive collaborations among various stakeholders striving for a shared resolution. Locally rooted and globally connected, universities offer significant opportunities to deliver against the Sustainable Development Goals (SDGs), working with researchers, educators, students and wider stakeholder communities (Purcell, 2019; Findler, et al., 2019). Because higher education institutions are locally rooted and globally connected, they offer significant opportunities to implement the SDGs in collaboration with faculty, staff and students, as well as their wider stakeholder community and alumni body (Findler, et al., 2019; Trencher, et al., 2014). Undoubtedly, by embracing the SDGs in pursuit of sustainability, universities can help drive change towards a fairer society and a better world (Findler, et al., 2019). However, sustainability is often on the fringes of mainstream subjects, with academic work in this area largely separated from campus operations and community services, leaving universities struggling to integrate sustainability into their governance and business models (Purcell, 2019; Evans, et al., 2015). In this context, the article attempts to fill the research gap on the sustainability efforts of European technical universities. It also presents the search for strategies, solutions and good practices in this area. The momentum behind citizen-driven research stems from the European Union's science policy, which places great importance on addressing diverse societal impacts in research endeavor’s and fostering broad partnerships, as evidenced in the Horizon programmers. Mariana Mazzucato's report ‘Mission-Oriented Research and Innovation in the European Union’ (2018) provides guidance on how European science can engage with societal stakeholders, shedding light on the future direction of European funding policies. The quadruple innovation helix framework outlines the interactions between universities, industry, government, the public and the environment in a knowledge-based economy. This framework's core lies in the concept of transdisciplinarity, which harmonizes these dimensions and their interrelationships. Therefore, it is transdisciplinarity that we will explore as a potential direction for implementing sustainable development at universities.

In recent years, transdisciplinarity has gained prominence due to it enabling knowledge exchange between scientific and non-scientific communities and offering a systematic approach to tackle societal problems (to name a few: Hadorn, et al., 2008; Bergmann, 2010; Jahn, et al., 2012; Lang, 2012; Giseke, et al., 2015; Fam, et al., 2020; Lam, 2021; Lawrence, et al., 2022). The collaborative process within transdisciplinary research can be categorized into three phases: co-design, co-production and re-integration (Bergmann, 2012; Schäpke, et al., 2018). A shared understanding of the problem, objectives and research questions is developed during co-design. Co-production involves the generation of new knowledge. Re-integration encompasses disseminating and potentially adopting the generated knowledge within both societal and research contexts (Bergmann, 2021).

It can be stated that the research community, the methodology and the knowledge are growing towards transdisciplinary research. Many alliances, platforms and repositories are being formed to communicate the diversity of transdisciplinary approaches, to strengthen the community through knowledge exchange and networking and to promote and reflect on the development and reflection of different methods and tools (https://itd-alliance.org/, https://td-academy.org/TD Academy, https://i2insights.org/, https://www.shapeid.eu/). Above all, they bundle the complex knowledge about transdisciplinarity and contribute to its dissemination and implementation at universities. Furthermore, a variety of handbooks for inter- and transdisciplinary knowledge production, method development and dimensions of participation and co-production have been published (Mc Donald, et al., 2009; Bergmann, et al., 2012; Durham, et al., 2014; Hemström, 2021).

Transdisciplinarity encompasses a combination of methods from diverse disciplinary and interdisciplinary fields, particularly in social and innovation research. It aims to forge new tools for co-production and collaboration. Rather than being a single method, transdisciplinarity functions as a principle or mode of integrative research, fostering a more intricate and adaptable approach to sustainable development. Conceptualizing integrative knowledge exchange between science and society (in a broad understanding including economics, politicians, administrations and civil society) aims to introduce transdisciplinary principles during the whole research process. This approach offers methodological pathways for research processes oriented towards solutions and transformations, converting societal issues into scientifically addressable questions. It facilitates the development of shared visions, solutions and transformations (Hadorn, et al., 2008; Bergmann, et al., 2010; Scholz, 2013; Giseke, et al., 2015). This reflexive and process-oriented research is conducted collaboratively among stakeholders, drawing upon local and academic knowledge of sustainable development challenges.

Transdisciplinarity is a research approach that fosters mutual learning between science and society while integrating diverse knowledge in problem-solving (Jahn, et al., 2012). It transcends the boundaries of scientific disciplines and bridges the gap between science and practice to develop integrated knowledge to solve societal problems (Td-net). On the other hand, transformation science observes and describes social transformation processes and actively initiates and facilitates change, learning from the process as a participant (Schneidewind, 2015). In transdisciplinary research, producing different forms of knowledge is crucial, including system knowledge, target knowledge and transformation knowledge. Systems knowledge is mainly analytical and descriptive. It is defined as knowledge about the current system or problem situation. Target knowledge is based on norms and values and relies on deliberation by different societal actors. This knowledge is about the desired future and values that indicate which direction to take. Transformation knowledge is focused on changing the problem in practice and integrating scientific knowledge about transformation and transferability (Hadorn, 2008; Wieck, et al., 2015; Buser and Schneider, 2021). By involving various stakeholder groups, transdisciplinary methods can provide more comprehensive insights into transformation potential, needs, future scenarios and problem solutions (Scholz, 2011; Schneidewind and Singer-Brodowski, 2014; Schneidewind and Augenstein, 2016; Di Giulio and Defila, 2018; Bruns, 2019).

Moreover, transdisciplinary education recognizes the importance of nurturing critical thinking skills in engineering students (Olmos-Gómez, et al., 2019). Beyond enhancing their abilities to question, identify

patterns and tackle undefined problems, transdisciplinarity strengthens their thematic progress. These conclusions support Harris's work (Harris, et al., 2010) on group metacognition through band interactions in music.

Although various methods and tools are available for conducting transdisciplinary research, support structures for promoting transdisciplinary research at universities are still limited. The institutionalization of transdisciplinarity as a research principle, encompassing comprehensive support and integration at both content and structural levels, is ongoing. While some universities have taken steps to implement transdisciplinary policies, there is a need for broader adoption and mainstreaming of transdisciplinary practices (Vienni-Baptista and Rojas-Castro, 2020; Ahrend and Podann, 2021; Vienna-Baptista and Thomas Klein, 2022). Notably, younger universities demonstrate a more substantial presence of transdisciplinarity in their structural and developmental planning (Leuphana University Lüneburg). Interdisciplinary and transdisciplinary education and training are still needed to institutionalize transdisciplinarity as a research and teaching principle. The ongoing advancement of methods and formats for knowledge exchange and circular transfer between science and society will play a crucial role in this institutionalization process. However, stronger political support will be essential in the future to foster more effective interfaces for sustainability issues (SDGs) and the integration of knowledge. This article represents a valuable contribution as it sheds light on the initial range of institutionalized support structures, addressing key questions related to transdisciplinary initiatives at partner universities within the ENHANCE Alliance.

3 Methodology

Exploring practices, ways of working and structures within the ENHANCE Alliance, the first research phase of the ENHANCERIA project aimed at attaining an overview of structures and practices, providing sustainable development through transdisciplinary research. Therefore, the research procedure used for this paper was built based on the analyzed transdisciplinary initiatives of the ENHANCE Universities. It includes three main steps (Fig. 1): research paradigm, data gathering and analysis. All research steps have been done interactive, including regular exchanges between the partner universities.

The research group involved in each phase of the research included representatives from the seven partner universities in the ENHANCE Alliance, namely Chalmers Tekniska Högskola AB, Norges Teknisk-Naturvitenskapelige Universitet, Politecnico di Milano, Rheinisch-Westfälische Technische Hochschule Aachen, Technische Universität Berlin, Universitat Politècnica de València and Politechnika Warszawska. The respondents in each university were teaching, and research staff were involved in projects, research and transdisciplinary activities at their universities. The respondents to the survey, interviews and workshops were highly experienced individuals with a high level of engagement in such activities.

The research paradigm (Fig. 1) was the phase of knowledge exchange about the research topic from both an objective (Fig. 1, Desk research analysis) and subjective (Fig. 1, Workshop Round 1, reflection of common approaches to transdisciplinarity) perspective. Round 1 of the workshops enabled the development of a table of key concepts for transdisciplinarity and their understanding from the perspective of each partner university. The workshop was attended by a dozen representatives from all seven partner universities. Participants were divided into several working groups to discuss as many concepts, terms and approaches to transdisciplinarity as a research principle for sustainable development and relevant to further research.

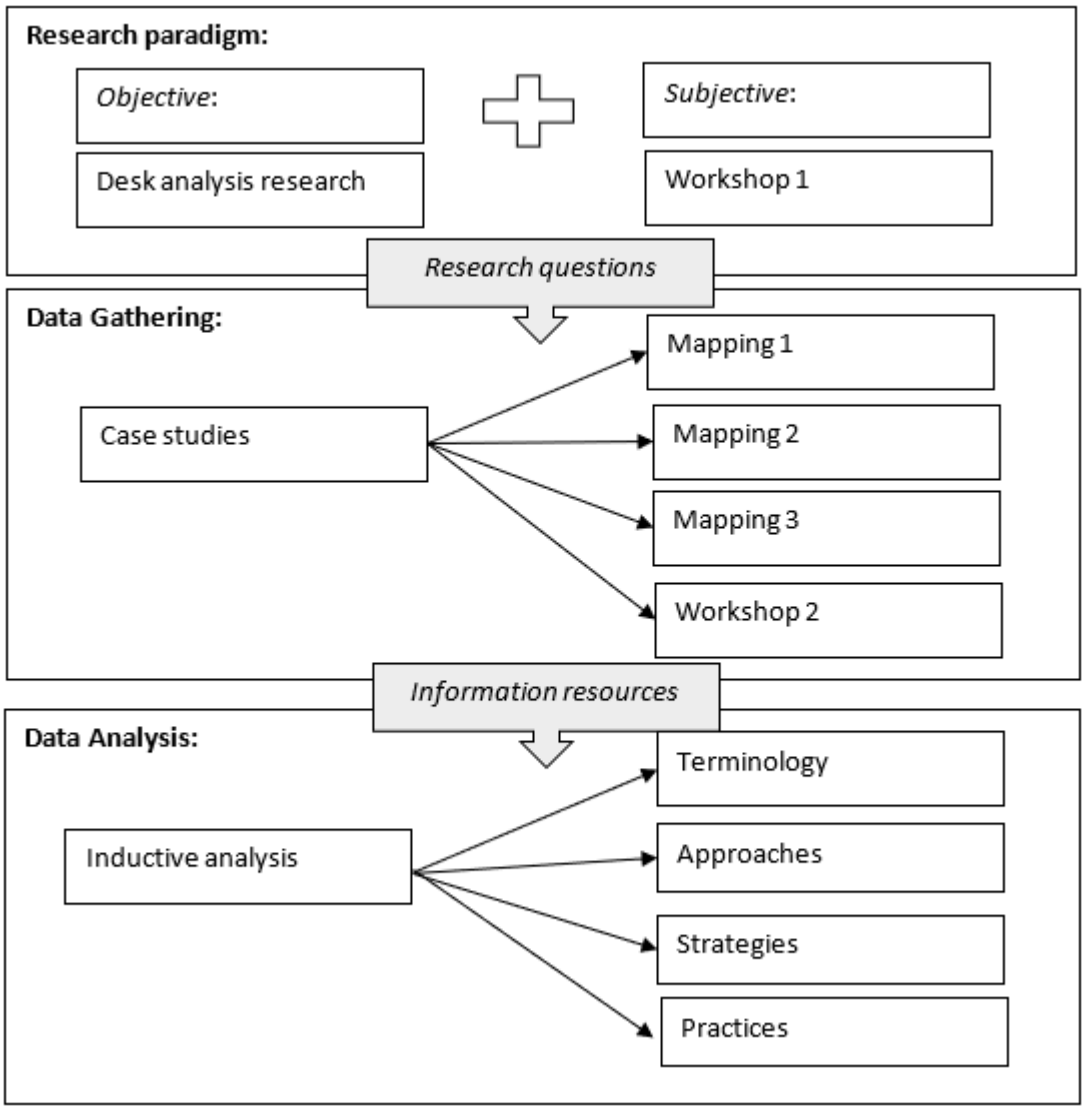

Figure 1. The research model.
(*Source:* Authors' own research basis MacIntosh and O'Gorman, 2015)

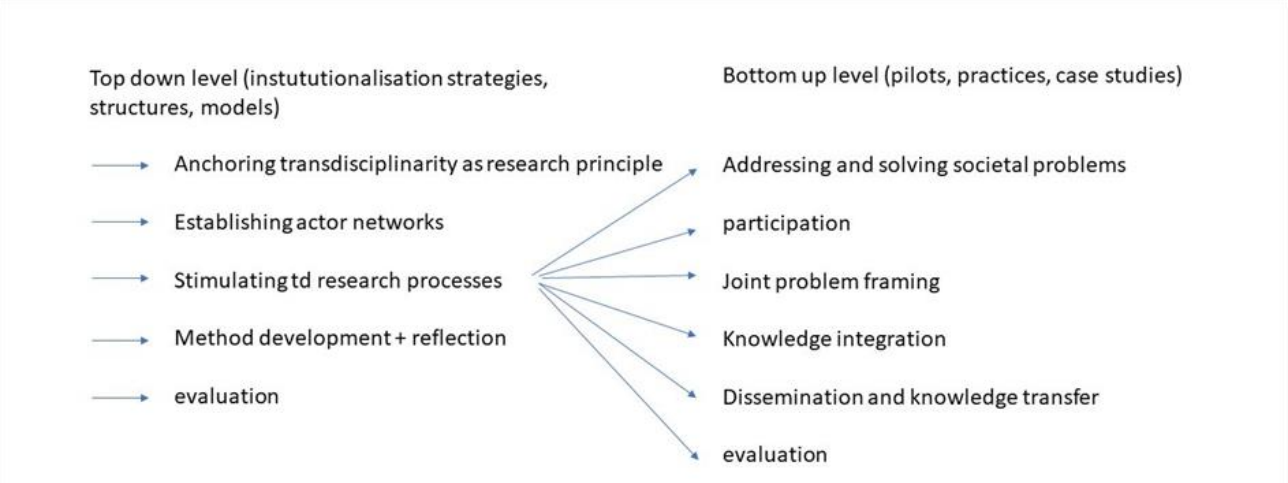

Figure 2. Framework for interview questions.
(*Source:* Authors' own research)

The results of both analyses allowed us to sharpen the main research questions towards a shared understanding of the diversity of conceptual approaches and channels for possible synergies:

RQ1: What is the common understanding of transdisciplinarity both conceptually and in practice among ENHANCE universities?

RQ2: How can the diversity of transdisciplinary approaches for sustainable development be characterized in terms of levels of engagement, and what are the associated differences in social impacts?

RQ3: How can universities enable and foster transdisciplinary approaches to sustainability?

Answering these questions was defined as the main objective of the research.

Next, the research based on the findings from the first research period of the ENHANCERIA project was performed using the following methods and the way of their implementation (Fig. 1, Data Gathering). Therefore, different mappings have been done. They provided a first inventory of structures, strategies, practices and terminologies for knowledge exchange between research and society. The mapping process in different rounds was based on a research survey and in-depth interviews with transdisciplinary project managers and further academics in strategic positions enabling and supporting transdisciplinary research from each of the seven universities.

Mapping Round 1 includes the use of short descriptions for transdisciplinary initiatives on a top-down (institutional supporting structures that foster sustainable development through transdisciplinary research) and bottom-up level (practices and projects of transdisciplinarity) (Fig. 2). All study cases contain the following information: goals, short project description (processes, components of projects or structures, principles), formats, methods or tools, and keywords. A total of 20 cases were submitted by universities (RQ1 and RQ2).

Mapping Round 2 includes the survey with specified questions related to the submitted cases and collection of new cases identified as transdisciplinary initiatives. The survey has included the following topics (beyond short project description goals and methods): thematic approaches, top-down level/bottom-up level, type of transdisciplinary initiative, involved stakeholders, drivers (mainly responsible for carrying out the initiative), initial funding, methodologic approaches, core mission and characteristics for transdisciplinary potential (knowledge production and dissemination). The seven universities submitted 40 cases, some of which specified the information of the case studies already identified (RQ1 and RQ2).

Mapping Round 3 conducts structured interviews to specify the contribution of the submitted projects for in-depth information for comparison and analysis and to identify further transdisciplinary initiatives and relevant contacts involved. The interview questions served to specify the contribution of the identified projects to sustainable development through transdisciplinary research at the ENHANCE universities. They were structured into basic superordinate questions (Fig. 2) about the established knowledge exchange between science and society. The specific questions were about the institutionalization of transdisciplinarity (top-down level of structures, strategies and formats) and transdisciplinary research processes (bottom-up level of pilot projects, case studies and practices). Representative and exemplary projects have been selected for the interviews to characterize the top-down and bottom-up levels (Fig. 2). The interview questions have also been used to collect further projects at the institutions (RQ1, RQ2 and RQ3).

Workshop Round 2: Aiming to develop integrated knowledge – also using one principle of transdisciplinary research (Hadorn, et al., 2008; Giseke, et al., 2015) – the mapping findings have been shared in different workshops among the ENHANCE partners. Highlighting Workshop Round 2, the differentiated processes, activities and strategies were jointly reflected in a workshop (RQ1, RQ2 and RQ3). The reflection focused on setting a methodologic approach for the analysis and comparison of the following paths:

- To show the range of possibilities, perspectives and understandings of transdisciplinary research within the ENHANCE Alliance to derive shared insights and joint research approaches from this.
- To present a selection of different good practice examples that demonstrate specific aspects of transdisciplinary research for sustainable development in terms of creativity and innovation and represented as possible role models for the other institutions.

As navigation through these two paths, the glossary for transdisciplinary research for the sustainable development with various related terms on participatory research, collaboration, co-production, co-design, etc. will be created as a growing document on the Miro working platform. The glossary will constantly expand as the work

in this focus area progresses, highlighting and addressing links between the terms.

Workshops are a specifically designed method to fulfil a predefined, though not predictable, goal (Ørngreen and Levinsen, 2017). Findings from literature studies indicate that workshops as a means are an authentic practice within the domain in question and generate guidelines on how to innovate and incorporate workshop frameworks into future situations (Wiek, et al., 2014; Mor, et al., 2012). Mapping is a group-based qualitative research method that allows participants to shape discussion on a topic. In the beginning, they helped target the mapping rounds, and during the research process, they facilitated the summarization of shared knowledge and coherence on the understanding of transdisciplinarity as a research principle. Mapping can better understand the connections between people, places and organizations over space and time (NCCFPE, 2017).

The case studies, survey results and interview content used during the workshop and the mapping rounds represent a first overview of possible, practical transdisciplinary initiatives on sustainable development at the institutions and form the information basis for a comparative consideration and analysis. The mapping of different transdisciplinary initiatives of the ENHANCE universities on the top-down and bottom-up levels provided the first inventory of structures, strategies, practices and terminologies for knowledge exchange between research and society (Fig. 1, Data Analysis). The structural approach of supporting transdisciplinary research strategically (top-down) and the project level of conducting transdisciplinary research for sustainable development (bottom-up) were used as search windows to identify relevant and appropriate co-productive initiatives for the focus area. This article is a first step to disseminate the obtained research results.

4 Results and findings

As a result of the mappings and the integrated knowledge production in the workshops, the representatives of focus area 1 in the ENHANCE Alliance agreed on a broadly shared understanding of transdisciplinarity, including keywords as well as a selection of good practice examples at the interface of strategic supporting structures and projects of transdisciplinary research for sustainable development. This paper presents the research findings in the context of answering the three research questions formulated above.

4.1 The need for a shared understanding of transdisciplinarity

This article delves into the motivation and expectations for achieving a shared understanding of transdisciplinarity as a research principle across ENHANCE Universities. This exploration is based on the various methods mentioned in the methodology. A broadly shared understanding of transdisciplinarity, including keywords and selecting good practice examples at the interface of strategic supporting structures and projects of transdisciplinary research for sustainable development, was discussed and reflected. These results are already published in the first deliverable of the ENHANCERIA project (Document discussing comparison, analysis including an enhanced glossary).

A common understanding of the need for shared learning from the partner universities on this research principle was essential to the discussions, even if it is titled with other keywords such as participatory research, co-production, collaboration or co-design. These approaches go hand in hand with the common concern for providing better access to participation for academics (researchers and students) and non-academic stakeholders and fostering the university's role as the foundation for working and knowledge exchange with society and circular knowledge transfer.

Another common fundamental expectation of the ENHANCE Alliance linked to transdisciplinary research is producing new knowledge aligned with a societal impact. Societal impact adds value by addressing societal problems and has been defined as a significant indicator of a shared understanding of transdisciplinarity. In other words, transdisciplinary initiatives often have a transformative agenda as the production of new and integrated knowledge needs to lead to social change.

Respondents of the interviews and survey and working group participants identified collaboration, cooperation, co-creation, co-exploration, co-design and co-production as the most commonly used participation methods and approaches in transdisciplinary activities.

Participants noted that inter-, multi- and transdisciplinary approaches exist side-by-side, often within the same organizational unit or research project. In addition, the explicit focus on societal challenges varied across transdisciplinary research and education activities alongside different levels of participation and engagement of non-academic stakeholders. Participants in this research also emphasized the importance of close contact with communities and their needs, a focus on mutual learning and knowledge exchange, and a focus on culture as a mediator for knowledge transfer between the university and the society. The need for new collaboration and communication solutions and new formats and methods, such as a digital twin platform or a digital communication environment, also emerged. At the level of the workplace dimension, respondents also stressed the importance of mutual engagement and the resulting synergies in collaboration. To achieve these goals, it is essential to be open to new working methods that lead to developing collaborative skills. Each new transdisciplinary project and initiative fostering transdisciplinarity should be seen as a source of this development.

In summary, a broad understanding of transdisciplinary is needed due to the wide variety of mapped initiatives at the ENHANCE Universities not only for analyzing transdisciplinarity as a research principle but also for the synergy created during collaboration between the involved stakeholders. The mapped transdisciplinary initiatives include a range of interdisciplinary, multidisciplinary, and transdisciplinary approaches. They also address societal challenges through collaboration and co-design to co-production. Transdisciplinary initiatives have different levels of engagement through the involvement of different academic and non-academic stakeholders, which will be elaborated on in the next section of this article.

4.2 The diversity of transdisciplinary approaches to sustainable development

Aiming to mainstream, optimize and provide structures for institutionalizing the knowledge exchange between science and society as a first approximation, it has to be stated that there is a large variety of transdisciplinary initiatives within the ENHANCE Universities in terms of understanding and approaching transdisciplinarity as a research mode. Viewing cooperation models, methods and formats of citizen involvement and knowledge exchange between science and society across the different institutions leads to a differentiation between top-down and bottom-up approaches to transdisciplinarity. Top-down referred to institutionalization strategies, supporting structures and methods for promoting transdisciplinarity, while bottom-up referred to pilots, practices and case studies conducting transdisciplinary research for sustainable development (Fig. 2). However, due to a different understanding of the underlying frameworks for the assignment, it became clear that a categorization based on this distinction is not possible. The interview respondents named various factors, such as funding, university guidelines and strategic approaches, as to why their initiative could not be categorized as either top-down or bottom-up. More in-depth, the genesis of the different transdisciplinary initiatives and their underlying frameworks at the institutions represent different research cultures, strategic objectives and university programmers for sustainable development and societal transformation. The mapping results in various initiatives such as cooperation models providing long-term alliances between science and society, research centers promoting inter- and transdisciplinary processes, social engagement programmers providing teaching and research training, and strategic platforms and services providing knowledge exchange testing and evaluating transformation.

As a result of analysis, the relevant, distinctive characteristics of inter-, multi- or transdisciplinarity in an overview are primarily delineated through the types of initiatives, their alignment and, notably, the levels of engagement and the resulting social impact. The levels of engagement correspond to the non-hierarchical types of engagement outlined by the European Science Engagement Association (EUSEA, 2023), which are 'informing and inspiring', 'consulting' and 'collaboration'. Table 1 shows some of the initiatives mapped to provide insight into different levels of engagement as well as the organizational level at which they have been institutionalized.

Table 1. Matrix with examples for positioning transdisciplinary initiatives in ENHANCE Alliance universities (*Source:* Authors' own research)

-	**University Level**	**Interdepart-mental Level**	**Departmental Level**	**Project Level**	**Course Level**
Collaboration	RWTH Campus GmbH	-	-	Autoferry at NTNU Restoration of the Church of San Nicolas in Valencia at UPV	Master's in Architecture and Planning Beyond Sustainability at CHALMERS
Consulting	STADTMAN-UFAKTUR at TUB	-	META at POLIMI	-	-
Informing	-	-	-	ACCorD at RWTH Innovation Hub at WUT	-

At the first level of 'informing and inspiring', stakeholder engagement or participation is minimal. This level's goal is to disseminate knowledge and stimulate thinking. In the case of transdisciplinarity, this can include policy recommendations based on transdisciplinary research. Within ENHANCE, various initiatives fall into this category, such as the Innovation Hub at Warsaw University of Technology (WUT), which disseminates knowledge about the links between science, innovation and business through information and promotional activities. Another example is the ACCorD Living Lab at RWTH Aachen University, a project including research, industry and policy partners that bundled and expanded existing testing tracks to include a freeway section, an urban area and a rural area in the 'Corridor for New Mobility Aachen – Düsseldorf', to systematically test and validate automated vehicles in interaction with networked infrastructure. All activities were embedded in extensive public communication and outreach activities to ensure long-term support for and use of the infrastructure beyond the project and interested external users.

At the 'consulting' level, the initiatives at this level promote shared understanding and promote and support decision making, such as social research, focus groups and advisory committees. One example is the strategic TU Berlin platform for living lab research STADTMANUFAKTUR. It links scientific questions, methods and data with projects, practical know-how and stakeholders. Furthermore, it facilitates matching between scientists and partners from politics, business, culture and civil society. The STADTMANUFAKTUR supports with consulting that transdisciplinary concepts and transformation knowledge may be jointly developed, and problem solutions can be tested and applied in an urban context and bundled in a shared knowledge pool.

Another example is the interdisciplinary interaction at the consulting level in the META project of Politecnico di Milano (POLIMI). This project aims to offer expertise in philosophical, social

and ethical issues related to the processes of science, technology and innovation. The network that this project has established includes outreach to citizens.

The 'collaboration' level is at the high end of the spectrum. Here, science and society engage jointly in participatory research, stakeholder dialogue and collaboration—for example, the Autoferry project, the Norges Teknisk-Naturvitenskapelige Universitet (NTNU), this initiative. The milliAmpere2 ferry is an autonomous all-electric passenger ferry for urban water transport. A large multidisciplinary team, including disciplines such as Design, Electronic Systems, Marine Science, Naval Architecture, Psychology, and business, developed the milliAmpere2. This project shows how collaborative research can develop new concepts and methods enabling innovation. Another example of a transdisciplinary initiative is the Restoration of the Church of San Nicolas in Valencia at Universitat Politècnica de València (UPV). The project aimed to completely restore the baroque frescoes from the 17th century in the Church of San Nicolás in Valencia, which included collaboration between stakeholders from civil society, administration and the university. Also, in the RWTH campus structure, more than 420 companies are represented on campus, allowing interdisciplinary research teams to work closely with industry partners on various subject areas. These are embedded in 16 long-term clusters. Initiatives on the 'collaboration' level often include educational courses like the master's programmer in Architecture and Planning Beyond Sustainability at Chalmers Tekniska Högskola (CHALMERS).

Furthermore, the mapping and analysis carried out by the ENHANCE member universities suggest that transdisciplinary initiatives with the highest levels of engagement have a higher social impact. Our research defines societal impact as a second relevant indicator as an added value, including a strategic orientation towards addressing and solving societal problems. Respondents and working group participants highlighted how difficult it is to evaluate and measure societal impacts. However, depending on the focus of the transdisciplinary initiative and its alignment with the ENHANCE university's strategic vision, societal impacts can be achieved or enhanced through the following means:

- Transdisciplinary Process Design: This involves initiating a collaborative process that begins with co-framing a societal problem, co-producing knowledge and reiterating/reflecting on the transferability for potential upscaling in the scientific and societal sphere. By fostering strong synergy among the various stakeholders, they become more engaged in the problem-solving journey, leading to increased receptivity to the research outcomes of the transdisciplinary initiative.
- Facilitating Knowledge Exchange and Integration: By providing and enabling knowledge exchange and knowledge integration for transdisciplinary research processes and projects in a long-term perspective. This approach supports a sustainable growth and development over time.
- Addressing Societal Challenges: Through advanced research areas/programmers and collaborative design of research concepts, prototypes, pilot projects and new values in strategic partnerships (e.g. with industries and companies), solutions are co-created to address societal challenges.
- Raising Societal Awareness: By emphasizing the necessity of co-designed solutions that integrate research and business teams with other stakeholders, society raises awareness about the importance of collaborative approaches.

To summarize, the mapped transdisciplinary initiatives at the ENHANCE universities vary significantly in focus towards the societal impact of innovative and creative strategies. As mentioned above, this depends on funding, strategic approach, methods and formats and, most importantly, levels of engagement. A broad common understanding of transdisciplinarity is needed to anchor this research principle as a framework in the ENHANCE universities and encourage further initiatives of knowledge exchange and collaboration between science and society for sustainable development.

Along with the diversity of the transdisciplinary initiatives at the ENHANCE alliance regarding the levels of engagements and societal impact, it is the basis to create synergies between the various stakeholders to promote the production and dissemination of new integrated knowledge fostering sustainable solutions for societal transformation. To facilitate innovative synergies, stakeholders need to be engaged and participate more closely in the research projects and transdisciplinary initiatives. As a result, the levels of engagement represented by selected good practice examples of the ENHANCE universities provide insight into how the collaboration between the stakeholders already takes place.

4.3 Organizational engagement that fosters transdisciplinary approaches to sustainability

While the levels of engagement show how the various stakeholders can participate in the transdisciplinary research, the organizational engagement shows how the ENHANCE Universities foster sustainability through transdisciplinary approaches. This is important to provide concepts and strategies for supporting and enabling transdisciplinary research for sustainable development.

Universities are large and complex organizations. They consist of multiple levels of governing boards, departments, faculties and research centers. Furthermore, the governance of universities is influenced by external factors such as regional, national or international funding schemes and policy requirements. National and international funding schemes, such as the Excellence Initiative in Germany or the HORIZON 2020 funding scheme of the European Commission, influence how and what kind of research universities perform. Furthermore, alliances such as ENHANCE also influence the research content of universities. However, for the analysis of this article, the focus is on the university structures, as this will provide insight into RQ3 and how universities can enable and foster transdisciplinary approaches. For our analysis, we have determined five levels within the ENHANCE universities where transdisciplinary initiatives are situated, as highlighted in Table 1:

- The university level: This dimension refers to the formal organizational setup within the university and is the highest level of organization to be analyzed. This involves the various departments, faculties and administrative units and how they collaborate to achieve common goals. The university level facilitates the communication and decision making across the different parts of the university.
- The interdepartmental level: This level focuses on collaboration between different academic departments or faculties within the same university. Initiatives at this level include joint research projects, joint teaching efforts or sharing research among different departments. Such cooperation encourages knowledge exchange across diverse academic areas.
- The departmental level: This dimension focuses on collaboration within individual departments or faculty. The transdisciplinary initiatives at this level involve research projects, researcher sharing or teaching efforts within the same department. This level of cooperation strengthens the research capabilities of the department.
- The project-based level: This dimension examines collaboration on specific research projects or initiatives. Researchers from different departments or faculties come together to work on a common goal-these types of collaboration lead to focused outcomes.
- The course-based level: Education is important to the university's identity and mission. It also plays an essential role in the ENHANCE universities' mapped initiatives. The course-based level refers to designing and delivering educational courses for the university's students on either a bachelor's or master's level. It often includes students from various educational programmers within the university and external stakeholders. It is essential to include these initiatives as education is the university's core mission and should not

be overlooked. Furthermore, education and research are often connected, so promoting transdisciplinary education will also influence research.

While categorizing the mapped initiatives, it became clear that most initiatives happen on either the university or course-based levels. That initiatives mainly happen at the university level can be explained by external factors, such as funding schemes and alliances, such as the ENHANCE Alliance. As an Alliance, ENHANCE encourages synergies between universities by organizing workshops and Walk & Talks as a new transdisciplinary format. During these events, colleagues within different universities with similar interests are introduced and encouraged to engage in discussions and knowledge exchange. Furthermore, all these external factors have a clear top-down aspect, which is easier to implement at a university-wide or interdepartmental level.

Furthermore, it can be challenging to place a transdisciplinary initiative within one department or faculty of the university, as these structures often still have a disciplinary character. This disciplinary character is a barrier to the introduction of transdisciplinary initiatives. These initiatives will take a backseat to the more disciplinary-focused research happening simultaneously. Therefore, the embeddedness of disciplinary culture is a challenge for transdisciplinary researchers. As the academic system favors disciplinary research, individual researchers can face personal dilemmas for their careers when pursuing transdisciplinarity (Ylijoki, 2022).

To summarize, analyzing where transdisciplinarity for sustainable development happens in the university organization will enable us to foster transdisciplinary initiatives. To get a better understanding of the complex organization of the university, we have divided the university system into five different levels. While mapping and analyzing the initiatives of the ENHANCE universities, a pattern emerged. The educational level mainly consists of transdisciplinary educational courses. This level allows the university to collaborate across various disciplines and with external stakeholders. As for the university level, this seems to be linked to some top-down characteristics of some of the initiatives. External factors, such as national or international funding schemes, influence them. Another factor is due to the nature of transdisciplinarity. Transdisciplinarity always includes two or more academic disciplines. Placing them within a disciplinary department or faculty can be difficult. This can lead to tension between the researchers of the various disciplines or the domination of one discipline over the other. These tensions can be minimalized by elevating these initiatives to university structures above the disciplinary departments.

5 Conclusions and outlook

The evaluation of transdisciplinary initiatives across the ENHANCE universities and the analysis of these initiatives during various research rounds have resulted in a comprehensive overview of the concepts and structures of transdisciplinarity and supporting transdisciplinary research towards sustainable development. These insights and knowledge will prove useful for researchers, managers, strategists and teachers in higher education and stimulate them to learn about the formats and strategies within their university and further develop them. With this research, we want to promote the implementation of transdisciplinarity as a research mode within higher education and to develop pathways for knowledge production.

However, aiming to support the gradual institutionalization of knowledge exchange between science and society is a first step across the ENHANCE Alliance. This article is a midterm overview of the findings of the ENHANCERIA project. To develop a joint transformation agenda to provide the Universities' role as drivers for sustainable development, it was important to create a mutual learning environment including all ENHANCE partners' perspectives and Universities' governance frameworks. We are using the first results of this overview for continuing exchange and sharing good practice examples to increase awareness of the importance of transdisciplinarity as a research mode for tackling sustainable development and achieving societal transformation. This is also a way to create the right environment for shared

learning among the ENHANCE Alliance and develop synergies. Therefore, specific formats have been developed for organizing the sharing of results and good practices, e.g. the Walks and Talks visits on-site integrating excursions to transdisciplinary project examples, presentations with strategy and research expertise and local interviews with stakeholders. Another result is a setup of key parameters and formats for establishing a pathway for enhancing the support of transdisciplinary research at the ENHANCE universities, e.g. with a catalogue of joint advisory for supporting transdisciplinary research. A further outcome of this evaluation will be the development of adapted toolkits and methods for making the knowledge exchange between science and society accessible, manageable and practical across the ENHANCE Alliance in the remaining funding period.

Therefore, insights include a comprehensive understanding of transdisciplinarity as both a research principle and policy at the ENHANCE universities. This understanding has been developed according to existing research and university governance structures with different orientations. The analyzed transdisciplinary initiatives range from interdisciplinary approaches to addressing societal challenges, cooperation models with businesses and city administrations, and the co-design of production and technology development at the interface of science, design and entrepreneurship. Additionally, the analysis looked at the slowly and differently established knowledge exchange between research and society and the involvement of societal actors at the ENHANCE universities.

Therefore, both levels of engagement and the societal impact are essential indicators of implementing transdisciplinarity that can and should be worked on, as they are crucial for achieving the projects' central objective, namely continual sustainable development and societal transformation. Through various interviews and reflections, we have identified effective strategies for achieving this objective and improving the quality of its achievement, such as fostering interdisciplinary reflection and knowledge transfer on transdisciplinary approaches and challenges. Another strategy is to create a mutual and inclusive learning environment encompassing the entire university and other interested parties, including external researchers and stakeholders, to encourage collaborative community building. Furthermore, an informal setting to allow candid discussions about failures and strategies for improving transdisciplinarity has proven valuable. It is also essential to strengthen the transdisciplinary research community, reinforce transdisciplinary approaches to research and fortify the knowledge base for transdisciplinary research.

However, there were also limitations to our research. Firstly, our research was limited to the seven ENHANCE universities, which restricted our dataset. Secondly, these institutions exhibited significant variations related to the development of transdisciplinarity as a mode of research and education for tackling sustainable development. Only a few established methods and tools exist for conducting the supportive structure promoting transdisciplinarity. This diversity posed a significant challenge in establishing a shared understanding of transdisciplinarity and raising awareness and capacities. Some universities focused on the technical definition of the concepts; others focused on the practical application. This made talks, discussions and workshops more difficult.

Further collaborative research on these strategies is needed. Alliances, such as ENHANCE, are essential in fostering an environment to develop these joint strategies and strengthened as they offer universities a platform to communicate and learn from each other. An ENHANCE platform for transdisciplinary research is an objective which integrates a framework for building structures for permanent knowledge exchange between science and society. It allows researchers to establish a transdisciplinary research community which encourages reflection, knowledge transfer and collaborative research on sustainable development. Another benefit of identifying and evaluating transdisciplinary initiatives is the compilation of different frameworks, strategies and concepts for integrating participatory research approaches and the ongoing knowledge

exchange between science and society. This identification and evaluation are an initial step towards making the institutionalization of transdisciplinarity more transparent and providing better support for creating a mutual learning environment within the ENHANCE Alliance, thereby enabling the further discussion and development of such strategies.

Several steps are essential to establish transdisciplinary research for sustainable development as an innovation ecosystem at ENHANCE universities. These steps include identifying the structural and strategic requirements for integrating this ecosystem and developing appropriate transdisciplinary methods and formats for addressing societal topics in sustainable development research. Moreover, developing suitable transdisciplinary methods and formats for grasping and working on societal topics in research concerning sustainable development is, on the one hand, a component of transdisciplinary research itself and, on the other hand, a building block for strategically better support transdisciplinary research initiatives at universities. The formats can, for example, map strategies for implementing and evaluating co-creative processes. Promoting competencies is necessary for researchers and students not only for transdisciplinary research and explicitly for knowledge integration but also for training civil society actors from practice to recognize them as knowledge carriers on an equal footing and to allow them to participate.

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