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Review

Review of transdisciplinary approaches to food-water-energy nexus: A guide towards sustainable development



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ABSTRACT

The burgeoning food-water-energy (FWE) nexus discussion for sustainable development reflects the ongoing transition from a silo-thinking to a transdisciplinary perspective in order to address challenges of the nexus practicability in real-world. Approaches to putting the FWE nexus into practice have failed to respond to the interdependent issues of resources appropriately and to devise the way societies are coordinated for such responses. Societies are critically important for advancing sustainable development and are thus placed at the center of the FWE nexus. Transdisciplinarity allows challenges to be framed and viable solutions to be found at the outset in an extensive and equal contribution of societies. This paper provides a systematic literature review to debate the current concepts and methods of the transdisciplinary research on the FWE nexus with the aim of developing a guide for socially inclusive sustainable development. Although the concept of transdisciplinarity has been widely accepted by nexus research, an explicit cognition of its practicability in real-world is still lacking, and sophisticated methodological development is required. As such, we proposed a conceptual framework to explore the potential contribution of transdisciplinarity towards linking FWE nexus practices and sustainability outcomes in real-world situations. This framework is useful in steering the management of nexus issues with integrative perspectives. Relying on the proposed framework, we made recommendations for successful transdisciplinary nexus practices. The future nexus research should be directed towards communication mechanisms and governance transition for balanced power relations among nexus actors, their representative selection, and timely involvement.

1. Introduction

In recent years, the need for integrating multiple sustainable development sectors has expanded the scope of interdependent dynamics within nature and society (Karpouzoglou et al., 2017). Demand for natural resources has continued to rise for decades, posing severe risks to humans and natural resources (Bleischwitz et al., 2018). Implementing Sustainable Development Goals (SDGs) in an integrated manner may come with additional demands. Comprehensive perspectives accounting for interdependencies of different resource use and the understanding of human relations with nature are needed. The recent debate on (food, water, and energy) resources nexus adopting transdisciplinary approaches addresses such interlinkages (Hoff, 2018). Transdisciplinary approaches provide the resources nexus with active stakeholders' engagement to identify and potentially control the influence of human behavior towards nature (Bergendahl et al., 2018).

This paper aims to review transdisciplinary debates on the food-

water-energy (FWE) nexus and to develop a research perspective on how a better understanding of human relations with nature can be utilized to deliver SDGs in an integrated manner. In this regard, after taking a close look at aspects that shape interconnections among SDGs (Section 1.1) and elements that define transdisciplinary FWE nexus (Sections 1.2 and 1.3), the way these two themes could be linked is expounded (Sections 1.4). We conducted a systematic literature review of relevant academic knowledge in this field to illustrate how current transdisciplinary nexus debates have been formulated in response to such interlinkages, and how they can be further improved.

1.1. What are the interconnections among the sustainable development goals?

Sustainable development goals are linked, and their interconnections lie in contextual considerations (Bielicki et al., 2019). The understanding of aspects that shape these interconnections is key to their

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effective, efficient, and coherent implementation. [International Council for Science \(2017\)](#) identified key aspects that shape interconnections among SDGs: directionality, context dependency, governance dependency, technology dependency, and time-frame dependency.

- The *directionality* describes ways these interconnections occur. It can be unidirectional, a one-way interaction that between two SDGs only one influence the other (such as the need of health care services for electricity access while energy generation does not rely on health care services). Moreover, there are some bidirectional interconnections among SDGs, a two-way interaction that between two SDGs both influence one another (for instance, climate mitigation actions such as reducing the greenhouse gas emission could constrain transport access, and vice versa, providing more transport access causes more greenhouse gas emission and subsequently exacerbating climate change). Furthermore, some SDGs interact circularly, a loop-relationship that multiple SDGs affect the other in turn.
- The *context dependency* stands for geographical relationships across the implementation of SDGs and their outcomes. The geographical relationships are not limited to natural contexts and can comprise different aspects of social contexts such as social behaviors, economic activities, and political interests. This dependency clarifies how knowledge can be generalized to other contexts.
- The *governance dependency* refers to the extent to which institutions and rights are strong enough to avoid making decisions on any sectors of the economy regardless of its stakeholders and whatever their legal status is. Adequate governance reduces the likelihood of negative impacts on stakeholders.
- The *technology dependency* points out the significant influence of technology on the achievement of SDGs. Although there is a transition towards environmental-friendly technologies such as electric vehicles, at present, there exist conflicts (e.g., continues fossil fuel extraction, land use changes due to an increasing space demand for private vehicle parking) with climate change mitigations efforts.
- The *time-frame dependency* refers to the fact that the implications of some interactions may be limited to real-time, while others may have time lags. For instance, the increasing use of fertilizers may boost agricultural productivity over the short-term while might well have longer-term impacts on access to food, and poverty.

The FWE nexus could potentially facilitate the management of these aspects and enhance the integrated achievement of SDGs ([Bleischwitz et al., 2018](#)). Although the FWE nexus reflects mainly on interconnections between SDG2 on food (zero hunger), SDG6 on water (clean water and sanitation), and SDG7 on energy (affordable and clean energy), there are several direct and indirect linkages between nexus thinking and other SDGs ([Pahl-Wostl, 2019](#)). The World Wide Fund for Nature organization presented the multiplicity of interlinkages between goals 2, 6, and 7 and the other SDGs (for more information see [WWF-SA, 2017](#)). In support of sustainability transition and delivering SDGs in an integrated manner from the lens of FWE nexus, transdisciplinary approaches are yet to be adapted ([Allouche et al., 2019](#)).

1.2. Why transdisciplinarity?

The challenges of ensuring resources security while adapting human-made technologies to environmental change require the involvement of a range of stakeholders. Issues such as climate change, water and energy use, agricultural management, and addressing ecological challenges are compounded by the need for socially and economically solutions ([Harris and Lyon, 2014](#)). These challenges require approaches that promote collaboration between multiple stakeholders from different disciplines, organizations, academic research, and practice. The stakeholder collaboration can be achieved through transdisciplinarity.

Transdisciplinarity allows challenges to be framed and viable

solutions to be found at the outset in a broad and equal contribution of stakeholders ([Stirling, 2015](#)). This approach allows a more practical and problem-driven perspective to real-world challenges and complexities ([Johnson and Karlberg, 2017](#)). Drawing on the generation of knowledge from different stakeholders, transdisciplinarity provokes debates over the need for alternative perspectives and more socially accountable collaboration ([Harris and Lyon, 2014](#)). The engagement of a range of stakeholders from multiple disciplines and interests in problem identification, framing, and analysis is the exact need of the nexus in shaping solutions to fit society's need and moving towards sustainability ([Wyrwoll et al., 2018](#)).

1.3. The transdisciplinary food-water-energy nexus

Given the variety of nexus definitions among literature, it is not only the interactions within ecological sectors that describe the nexus, but also the social actors whose behavior interrelates with environmental sectors define the nexus ([Bleischwitz et al., 2018; Endo et al., 2017](#)). A transdisciplinary perspective on the nexus guides both the integration of knowledge from science and society, including local knowledge and the problem orientedness of concerns that presents real-world situations of social-ecological interactions.

Regarding the overall notion presented in the literature, this paper discusses three main elements that define the FWE nexus from a transdisciplinary perspective.

- *Key drivers for integration:* actions on the FWE nexus should form a problem-driven process accounting for the issue of concern, governance system, and stakeholders ([Daher et al., 2017; Hamilton et al., 2015](#)). Interdependencies between humans and nature mean that one environmental problem (e.g., low water quality, or extreme flood/drought) can cause other social and economic issues (e.g., lack of social equity, or low level of well-being) and vice versa. Such issues can be linked either directly, for instance, poor water quality often links to reduced river flows, or indirectly, for example the use of geothermal heat provides clean energy and food expenditures. The issues are defined depending on stakeholders and their position in a system (in terms of system governance) ([Pahl-Wostl, 2007](#)). The governance setting of the system, including both social and ecological contexts, refers to the degree of interventions carried out to enhance system process and stakeholders' interactions. Stakeholders can be individuals or interest groups associated with the sources of the problem, as well as those affected by the problem. Such governance settings that involve stakeholders tend towards transdisciplinarity.
- *Characteristics of the systems to be integrated:* Given the interdependencies between social and ecological systems, a detailed understanding of each is essential for further improvements on their integration and sustainability achievements. The social system refers to all human-related aspects that influence or are influenced by the "issue of concern," and may include different sectors of economy, politics, and technology. These aspects depend on human behavior towards all services provided by the natural system. Hence, in order to understand environmental problems and support intervention policies, it is essential to understand the underlying human drivers ([Hamilton et al., 2015](#)). The inclusive engagement of a wide range of stakeholders in nexus research and practice, which refers to the term transdisciplinarity, supports the required understanding of human drivers.

The natural resources (e.g., food, water, and energy) are also on the other side of this interrelated system. Given the fact that natural resources do not operate in isolation, the recognition of their influences on one another is required. Resource flows in the environment where output(s) of one resource is treated as input(s) for another and the circular dependency among resources put a holistic perspective on the

recognition of the natural system (Dyer et al., 2014). The engagement of multiple disciplines studying such ecological dependencies with nexus research has been ascertained through transdisciplinarity.

In addition to interrelations within social and ecological systems, potential interactions among the two systems that can be recognized and monitored through actions require attention.

- *Thresholds to actions:* actions to the FWE nexus need incentives in order to address certain trade-offs, exploit synergies, and achieve resource optimization (Kurian, 2017). The distribution of risks to such achievements, in turn, defines thresholds to nexus actions. It is essential to understand how stakeholders shape thresholds to actions in decision-making and management processes (Scott et al., 2015). Hence, the understanding of institutional capacity in order to respond to environmental risks, and externalities for the prioritization of decisions is essential to a comprehensive nexus perspective.

The three key transdisciplinary nexus elements highlighted above intend to capture both the integration of different sectors of social-ecological systems and the operational aspects related to incorporating different types of information, perspectives, and practices. Within the outline of these elements, it is apparent that the transdisciplinary nexus perspective aside from interdependencies among different sectors of the economy targets risks that ecological and societal components may potentially pose to each other.

1.4. How does a transdisciplinary nexus perspective potentially support SDGs integration?

The sustainable development goals are interlinked, and the transdisciplinary FWE nexus plays a significant role in the achievement of these goals in an integrated manner (Biggs et al., 2015; Saladini et al., 2018; WWF-SA, 2017). Fig. 1 illustrates how transdisciplinary FWE nexus could potentially support SDGs integration.

- The variant *directionality* of sustainable development sectors may be under control if the human attitude towards services provided by the environment lies in the efficient use and climate-change mitigation skills (Kurian et al., 2018). In case of training human in how to avoid throwing natural orders into disorder, such interactions among different sectors of sustainability stand stable. The transdisciplinary FWE nexus approach through *controlling human-related drivers of environmental risks* (e.g., deforestation, waste, pollutants) contributes towards **cooperative interactions** (Bergendahl et al., 2018). Cooperative interactions can be achieved through training purposes of transdisciplinarity.
- The *context dependency* of solutions to the integrated implementation of SDGs pushes policymakers towards **localized interventions** (Kurian et al., 2018). Urban areas are diverse in terms of natural resources availability, capacity to meet human demands, and the way users behave towards resource preservation. Significantly, any social-ecological related decision should be taken according to the related setting (Hoolahan, Larkin, et al., 2018). This context-based perspective is what the transdisciplinary FWE nexus emphasizes. The transdisciplinary nexus approach clarifies the *environmental, economic, and institutional status quo* through involving a range of relevant stakeholders, and subsequently, supports localized interventions (Allouche et al., 2019).
- The likelihood of SDGs integration in practice highly depends on *the extent to which stakeholders are involved in decisions and are influenced by actions* (International Council for Science, 2017). These dependencies are exactly what transdisciplinary FWE nexus targets for the integrity of ecosystems. From the transdisciplinarity perspective, forming a **resilient alliance** among stakeholders and linking their ideas through their direct, continued, and equal involvement in decision makings support the *governance dependency* of sustainable

development actions (Howarth and Monasterolo, 2017).

- Given the increasing role of *technology-based* interventions in sustainable development applications, the FWE nexus stresses on *thresholds to actions* (Kurian, 2017). The transdisciplinary perspective looks for **efficient resolutions** to adapt the use of technology for interrelated socio-ecological demands through building institutional capacity and managing externalities that may pose potential risks to the settings (Siegner, 2018).
- Given the variations of the implications of ecological performances over time, nexus emphasizes the need for comprehensive control over adverse conditions. It is essential to know *the extent to which stakeholders can adapt to the new situation or mitigate adverse consequences* (Howarth and Monasterolo, 2017; Wyrwoll et al., 2018). Transdisciplinarity contributes to the *time-frame dependency* of sustainable development through learning actions aiming **adaptive capacity**.

Though transdisciplinary FWE nexus may potentially be influential in the integrated management of sustainable development sectors, its critical engagement with empiricism is limited and challenging.

Given the coordination of information flows among multiple actors within the transdisciplinary nexus process, the key driving barriers are varying levels of knowledge, incompatibility of data from multiple sources, and data accuracy (Johnson and Karlberg, 2017; Kurian et al., 2018; Mohtar and Daher, 2019). Moreover, the availability of appropriate information across a variety of systems and actors is a concern over multi-stakeholder engagement (Basheer et al., 2018; Givens et al., 2018; Wolfe et al., 2016; Xue et al., 2018). Concerning active interactions among multiple actors, incompatibilities within and between institutional and social network structures lead to undesired dynamics and low levels of communication (Bergendahl et al., 2018; Halbe et al., 2015; Pardoe et al., 2018; Treemore-Spears et al., 2016; Villamor et al., 2018). Furthermore, the availability of stakeholders, their willingness for collaboration, their power relations, and the timely inclusive decision- and policy-making add complexities to practical experience of transdisciplinary FWE nexus (Covarrubias et al., 2019; Howarth and Monasterolo, 2017; Kumazawa et al., 2017; Matthews and McCartney, 2018; Ziv et al., 2018).

Within the leading scientific nexus debates, the effective way to rise to the challenges of transdisciplinarity is rarely questioned but frequently discussed as a concept into the environmental resources' sustainability. This scientific shortcoming calls for a comprehensive review of, and critical reflection on, existing discussions of the transdisciplinary FWE nexus to guide towards an effective route into the empirical practices that enhance multi-stakeholder engagement, socially acceptable decisions, and sustainability outcomes. Hence, the authors deem it necessary to critically investigate transdisciplinary nexus approaches before further endorsing the FWE nexus solely as a resource governance framework regardless of probable reflections on stakeholders and its practicability towards sustainable development. Through conducting a systematic literature review adopting a discourse analysis technique, the authors describe how scientific discourses have put transdisciplinary perspectives on nexus performances towards sustainability.

Following sections describe how scientific discourses were selected for the systematic review of the transdisciplinary FWE nexus and how these documents were analyzed (Section 2). Next, in Section 3, the paper presents its findings that characterize the diversity of transdisciplinary nexus approaches and methods in the reviewed discourses and derive key features of effective transdisciplinary actions from the body of the literature. Our findings are at the forefront of the need for FWE nexus methods that advance scientific understanding of multiple stakeholders' collaboration, inclusive and legitimate policies, and sustainability outcomes. To support further development of transdisciplinary approaches to the FWE nexus, this paper highlights empirical evidence of the FWE nexus debates for transdisciplinarity that explicitly

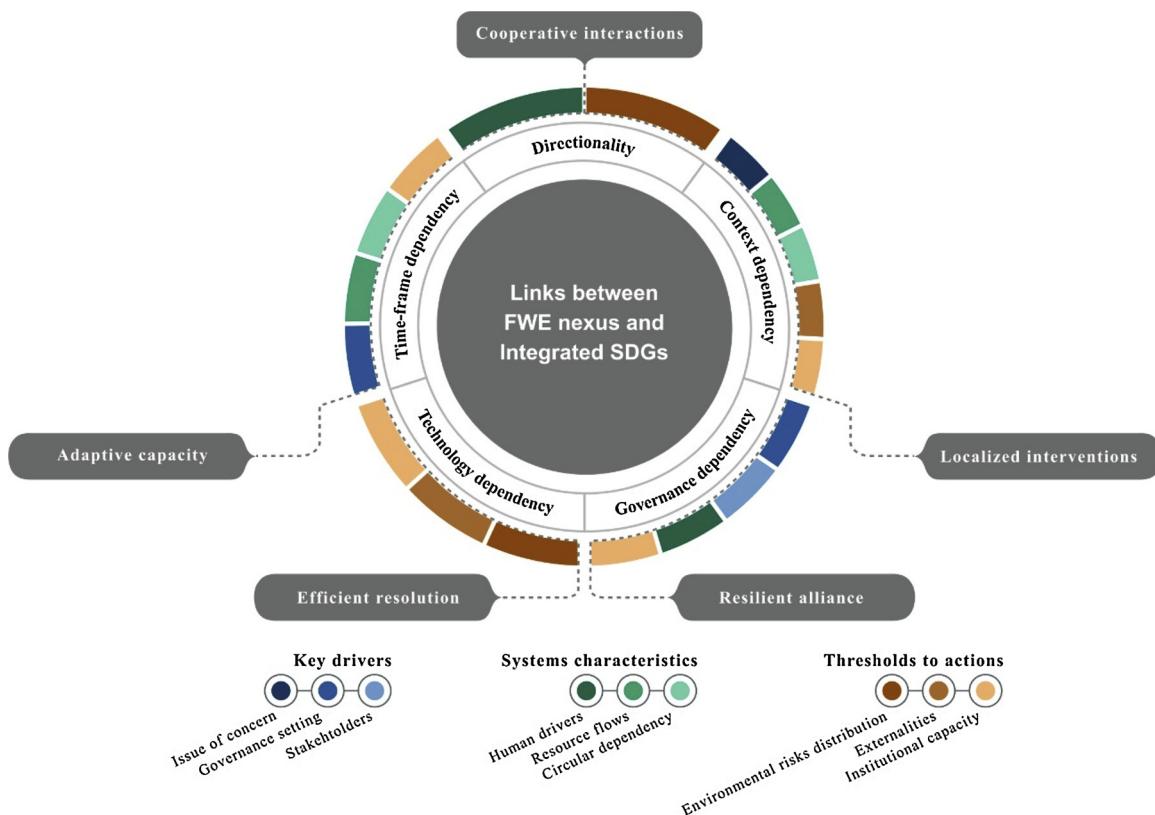


Fig. 1. The potential contribution of the transdisciplinary perspectives on FWE nexus to the achievement of SDGs in an integrated manner. Sections of the inner circle illustrate different aspects that shape SDGs integration. Colored sections of the outer circle present different elements of the transdisciplinary FWE nexus that contribute to the management and control of aspects of SDGs integration. Dashed lines show how the two themes (i.e., transdisciplinary FWE nexus and SDGs integration) could be linked. The grey text boxes reflect on potential outcome of such linkages among transdisciplinary FWE nexus elements and aspects of the SDGs integration.

Source: Adapted from Bazilian et al. (2011); Biggs et al. (2015); Bleischwitz et al. (2018); Daher et al. (2017); Davis and Andrew (2017); de Grenade et al. (2016); Endo et al. (2017); Harwood (2018); International Council for Science (2017); Kurian (2017); Pahl-Wostl (2019); Saladini et al. (2018); Schulterbrandt Gragg et al. (2018); Scott et al. (2015); WWF-SA (2017).

address social and political contexts and deeply engage with multiple groups of stakeholders. The paper highlights the required improvements for further practical developments of the transdisciplinary perspective on FWE nexus.

2. Methodology

This paper aims to systematically review the current transdisciplinary nexus debates from a qualitative standpoint. A systematic review is a detailed and transparent means of gathering, appraising, and synthesizing scientific evidence to answer a well-defined question (Boland et al., 2014). The main question this review intends to answer is: what is the state-of-the-art for using transdisciplinary approaches within the FWE nexus to guide sustainable development. Given the qualitative perspective of this paper on the review question, the study of numerical data from the reviewed literature (meta-analysis) is not included in the procedure of the systematic review.

Among several qualitative approaches that are optimal for systematic literature review (such as theme analysis, classical content analysis, and narrative analysis), the discourse analysis approach lends itself to a detailed identification of ideas, concepts, and categories through which we understand alternative interpretations and policy options (Onwuegbuzie and Leech, 2012). Discourse analysis is an interpretive research approach that helps to reveal multiple competing knowledge claims within leading discourses (Feindt and Oels, 2005). In the realms of environmental politics, discourse analysis raises awareness of the process through which policy challenges are constructed. It

shows how a particular understanding of environmental issues gain dominance, and how its associated knowledge is legitimized while other ways of knowing are marginalized (Waitt, 2010). Apart from shaping environmental politics, discourse analysis also manifests in social practices and institutional capacities (Wiegand and Bruns, 2018). Within the field of FWE nexus, discourse analysis can show how dominant perspectives on multi-stakeholder engagement emerge from particular knowledge and power relations, and how practice makes use of it.

To build a benchmark, this paper took the discourse analysis approach to study international research and practices on the transdisciplinary FWE nexus. Following sub-sections (2.1 and 2.2) describe how the required corpora for the aimed discourse analysis were compiled and analyzed.

2.1. Corpus compilation

Intending to analyze scientific nexus discourses on transdisciplinarity, this review paper established a set of selection criteria that allows the detection of discursive structures within mostly relevant and leading academic literature (Table A1). The inclusion of different online scientific databases, language, frequency of dominant keywords describing the subject of the study, and timeframe are the main selection criteria this review paper adopted for the discourse analysis stage. Documentary data were compiled in large text corpora under selection criteria reflecting the research question (Fig. 2). The final corpus includes 68 academic publications (Table B1).

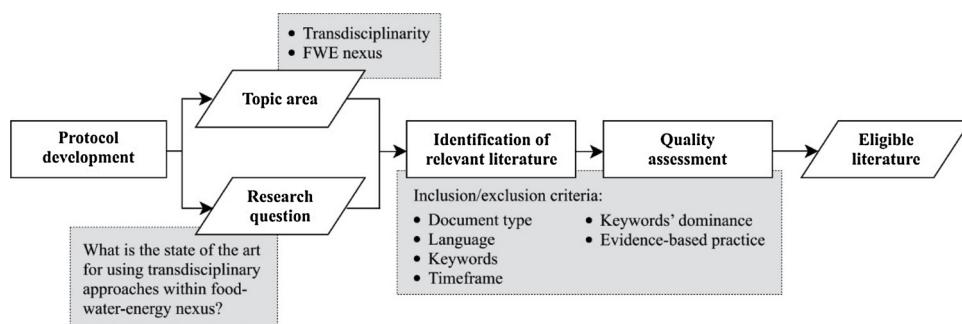


Fig. 2. Multiple phases of data selection for the systematic literature review about transdisciplinary approaches to food-water-energy nexus.

The academic publications for this review paper were selected from three different online databases: Scopus, Web of Science, and ScienceDirect ensuring the comprehensiveness of the final text corpus (last accessed 22.07.2019). Selected publications included international academic literature in various document types comprising peer-reviewed articles, proceedings papers, books (chapters), and editorial materials. However, to ensure data quality, coherence, and comparability, this paper only selected peer-reviewed papers and scientific books (or book chapter).

Within the online databases, this review paper used keywords *food*, *water*, *energy*, *nexus*, and *transdisciplinarity* for the relevant corpus compilation. Although the term food-water-energy nexus is dominant through current scientific debates, other possible combinations were also used of the three *food*, *water*, and *energy* words. In addition, multiple synonyms of the word *transdisciplinarity* such as *participation*, *governance*, and *collaboration* were included in the search string.

To ensure consistency of the review approach, documents with the less frequent expression of keywords and no response to key components of the research question were excluded. The PICCOSS framework identifies structures of scientific discourses based on key components of the research question (i.e., population, intervention, comparator, outcomes, study design, and setting) (Table A2). Documents were screened automatically for the low-keywords-frequency exclusion and were screened manually based on the PICCOSS framework.

Although this paper compiled the final text corpus in a controlled, transparent, and comparative way through multiple online databases using all relevant combinations and synonyms of keywords, several limitations are associated with this approach. By restricting search results to only publications in English, discourses in other languages are disregarded for the interpretation. Moreover, by focusing solely on resources available online and publications in full-text format, the analysis may miss out on the most up-to-date evidence such as abstracts (Boland et al., 2014).

To compensate for the risk described above, discourse analysis adopts an in-depth interpretive research approach. The final 68 selected publications were analyzed to frame the structure of the FWE nexus discourses around transdisciplinary approaches, outline the development of international concerns about multiple stakeholder engagement within the FWE nexus research and practice over time, and compare debates.

2.2. The discourse analysis procedure

The in-depth analysis of the compiled discourses was carried out through coding within the qualitative software ATLAS.Ti. The coding was conducted initially based on known categories of concepts describing transdisciplinary nexus debates and then was inductively complemented based on the interpretation of the reviewed publications. The final coding scheme focuses on four main questions:

First: "what are the underlying scientific trends in nexus publications towards transdisciplinarity?". This question investigates the

extent to which the multi-stakeholder engagement purpose formed most legitimate knowledge on linking nexus and sustainability concerns. In this regard, the authors coded the compiled corpora as follow:

- Research scope for multiple stakeholder engagement (including community): Nominal engagement, little more than display only to give legitimacy to development plans and does not lead to any change; Instrumental engagement, a means towards the efficient use of the skills and knowledge of stakeholders; Representative engagement, giving stakeholders a voice in decision-making and implementation of policies that affect them; and Transformative engagement, focusing on the empowerment of involved stakeholders (White, 1996).
- Research sustainability concern (regarding Fig. 1, to explore the extent to which nexus research involves multiple stakeholders for sustainability purposes): Directionality, context dependency, governance dependency, technology dependency, and time-frame dependency.
- Research emphasis on different aspects of nexus transdisciplinarity (regarding Fig. 1, to identify the aspects of nexus application that most hosted the involvement of multiple stakeholders): Key drivers, systems characteristics, and thresholds to actions.

In addition, this stage also explores the geographical extent of the transdisciplinary nexus discourses by analyzing the origins of knowledge production and destinations of their study in terms of case areas.

Second: "what are dominant concepts describing the transdisciplinary nexus debates?". This question examines different interpretations of this conceptual term and its development direction. In this regard, the authors coded the compiled corpora based on the most frequent keywords appeared within the entire text (e.g., governance, policy-making, transdisciplinary, and stakeholders) to conclude leading conceptual descriptions of the transdisciplinary FWE nexus.

Third: "what methods have supported transdisciplinary nexus practices, and to what extent do they meet potential outcomes of links between FWE nexus and sustainable development (given Fig. 1, the grey boxes)?". The authors identified dominant transdisciplinary methods that have been used within the reviewed publications (e.g., workshops, learning-based gaming, and participatory observation). Then, the compiled corpora were coded based on the identified transdisciplinary methods to explore their achievements in different contexts. Findings provide a deeper understanding of each method, their contribution to the transdisciplinarity concept, and the extent to which they support sustainability concerns within nexus applications.

Fourth: "what is the empirical evidence in transdisciplinary nexus applications?". This question examines the key driving forces of the transdisciplinary nexus practices. The authors pointed out experiments that addressed transdisciplinarity challenges and their associated solutions towards sustainable development.

Addressing these questions is important since a deeper understanding of social inclusion within nexus thinking, in other words, the

transdisciplinary nexus application is gaining dominance.

3. The status quo of transdisciplinary fwe nexus

In recent years, to enhance multi-stakeholder engagement within the FWE nexus, the adoption of transdisciplinary approaches has attracted increasing attention. Initially, the concept of the transdisciplinary FWE nexus emerged within the realms of international politics under the influence of the United Nations (UN) (Bergendahl et al., 2018). Biggs et al. (2015), for instance, traces the transdisciplinary FWE nexus back to 2015, when the United Nations pushed forward new goals of the post-2015 sustainable development agenda to actions aimed at achieving sustainable water consumption, energy use, and agricultural practices, as well as promoting inclusive economic development. Messages from the Bonn2011 nexus conference added overarching principles to the aims of the sustainable development agenda: setting the right incentives, mechanisms for policy coherence, and local empowerment (Hoff, 2011). These international communities (the UN and the Bonn2011 nexus conference) set the tone for future debates by arguing that a transdisciplinary approach to the integrated management of FWE resources may better accomplish SDGs.

3.1. The trend of transdisciplinary FWE nexus discourses

Since 2015, the significance of transdisciplinary approaches has emerged in the nexus literature with exponential growth in the number of publications in 2018. The transdisciplinary nexus research has voiced growing concern over the integrated study of FWE nexus and sustainable development (Fig. 3). Scientific discourses have purposefully integrated social and political aspects of the FWE nexus along with environmental concerns (Wiegble and Bruns, 2018).

The understanding of the social structure and political context helps to explore responsibilities of different stakeholders for the implementation of sustainability innovations and thereby provide critical reflection for the required governance system within nexus applications (Foran, 2015; Halbe et al., 2015; Keskinen et al., 2015). Therefore, at early stages, the trending nexus transdisciplinary research tried to unpack key drivers of nexus application and any likely threshold to their actions. Gradually, research has included more aspects of the FWE nexus and sustainable development in studies and subsequently, through multi-stakeholder engagement, in practice. Fig. 3 reveals that there has been a gradual increase in adopting higher levels of stakeholder engagement within nexus applications.

Stakeholders of the FWE nexus applications have been engaged variously in research and practice. Depending on the context and its associated challenges in taking advantage of knowledge and skills of the influenced population in making decisions and developing policies, research has involved stakeholders variously. From Fig. 3, it can be seen that the higher levels of engagement in terms of active stakeholders' involvement in making decision and empowering their skills for adaptive actions have become dominant recently.

Although the transdisciplinary research may bring about extensive knowledge integration, there are some limitations to the inclusion of multiple stakeholders in the FWE nexus practices. Given the geographical interpretation, the adoption of transdisciplinary approaches to the FWE nexus discourses may limit actions within specific geographies (for example, language barriers).

Transdisciplinary nexus practices depend on a common language between scientific communities and local stakeholders for knowledge sharing and collaborative discussion (Howarth and Monasterolo, 2016). More than 70 percent of actions that have been done in the field of transdisciplinary FWE nexus is situated within areas having linguistic commonalities with an author's location.

3.2. Conceptual description of the transdisciplinary FWE nexus

The ongoing debates on transdisciplinary FWE nexus serve multiple conceptual descriptions. First, it acts as a *sustainability transition concept* to support responsibilities of different stakeholders for the implementation of innovations in resource governance and sustainable development (e.g., Halbe et al., 2015; Karpouzoglou et al., 2017; Treemore-Spears et al., 2016; Xue et al., 2018; Ziv et al., 2018). Second, it serves as a *social inclusion concept* to facilitate negotiations over sustainable management of resources among multiple stakeholders from politics, academia, and private sectors to community (e.g., Bergendahl et al., 2018; Kumazawa et al., 2017; Mohtar and Daher, 2019). Third, it aims at a *transparency concept* to establish collaborations on trust and subsequently encourage stakeholders, especially non-experts, in their intention of collaborating in the nexus thinking and other related policy-making processes (e.g., Daher et al., 2019; Howarth and Monasterolo, 2017; White et al., 2017). Fourth, the transdisciplinary FWE nexus is employed as a *convergence thinking concept* to reach a consensus of opinions and ensure reliability and legitimacy of decisions (e.g., Johnson and Karlberg, 2017; Martinez et al., 2018; Wolfe et al., 2016).

Actions have operationalized the conceptual descriptions of the transdisciplinary FWE nexus variously depending on their purposes. Since the nexus concept emerged initially from a global point of view and most actions were taken on a global scale, the transdisciplinary nexus concept also had initially focused on the challenges of engaging stakeholders and converging their interests across geographical borders (Lawford et al., 2013). The argument of resource commonality across geographical borders makes the operationalization of the transdisciplinary nexus concepts more diverse (Daher et al., 2019). Some studies focused on the way stakeholders are engaged across the geographical borders (e.g., Al-Saidi and Hefny, 2018; de Strasser et al., 2016) while some emphasized the level of their engagement (e.g., Dombrowsky and Hensengerth, 2018; Soliev et al., 2015). Some researchers have also explored the necessity of active engagement of stakeholders from different areas of society in all phases of knowledge development for a real insight into needs (see Howarth and Monasterolo, 2016; Wolfe et al., 2016).

To overcome these concerns within the FWE nexus practices, proper transdisciplinary approaches are required.

3.3. Methods for transdisciplinary research on the FWE nexus

Several approaches have contributed to the development of the transdisciplinary FWE nexus. Among dominant statistical and environmental modeling approaches to the FWE nexus measurements, social approaches have recently contributed promisingly to the transdisciplinary aspect of nexus applications. Johnson and Karlberg (2017); Mochizuki et al. (2018); Sušnik et al. (2018) discussed that effective action to the transdisciplinary FWE nexus depends on how stakeholders frame the issue and interpret the knowledge. Within the FWE nexus research, several social methods emphasize the understanding of stakeholders' behavior, their way of thinking, and their ideas through direct observation or communication with participants. These methods include workshops, participants observations, gaming practices, and so forth.

Depending on research purpose and the scheme through which it serves multiple stakeholder engagement, nexus researchers have experimented with various methods. Our review reveals key purposes of the nexus research for adopting transdisciplinary methods as envisioning, experimenting, and learning.

An inspiring vision entails a narrative of the desired society based on shared principles of sustainable development and provides long-term guidance (Nevens et al., 2013). A process of envisioning engages and commits stakeholders with different perspectives. The envisioning purpose has been targeted frequently by nexus researchers who have

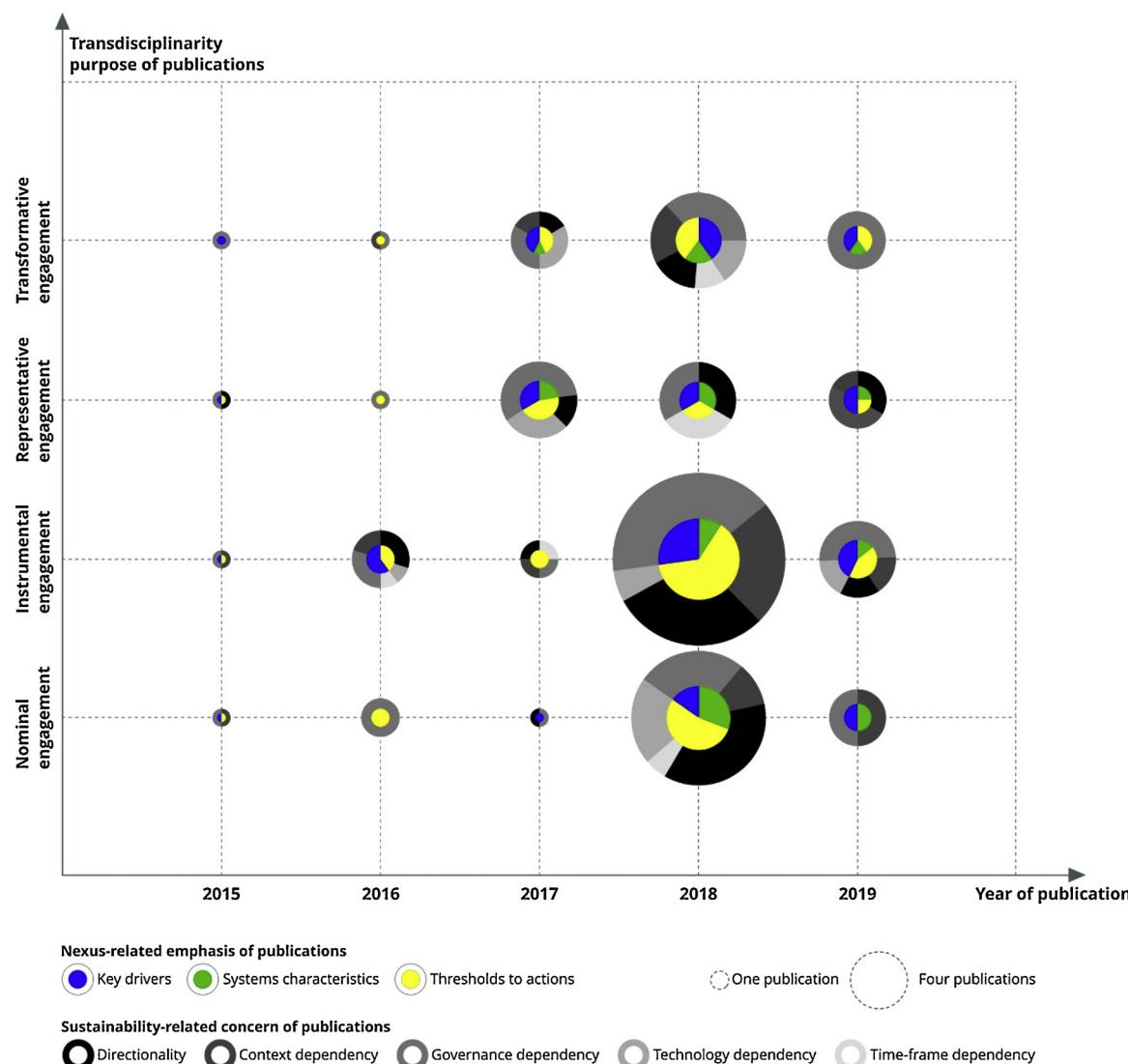


Fig. 3. The increasing trend of transdisciplinary FWE nexus publications (from Scopus, Science Direct, and Web of Science, last accessed 22.07.2019). Any circle at the intersection of the X (date of publication) and Y (transdisciplinarity purpose of research) axes illustrates number of publications at that moment having the specific associated purpose (regarding size of the circle), the extent to which they emphasized the FWE nexus (regarding the inner colored circle), and the extent to which they concerned sustainability aspects (regarding the outer colored circle). The bigger the size of the circle and the more the number of its colored subdivisions, the more relevant the publication is to the purpose of linking nexus and sustainability concepts. In addition, the number of publications over the Y-axis illustrates that research has experimented with increasing inclusion of multiple stakeholders, including community, within nexus applications. The lower number of publications that adopted higher levels of stakeholder engagement compared with those adopted lower levels of stakeholder engagement indicates the existence of challenges in doing so.

come up with the essential role of stakeholders in exploring the range of potential actions on the future of a transition pathway (e.g., Daher et al., 2017; Endo, 2018; Yung et al., 2019).

Following an inspiring vision, different experiments on how to realize the desired future situation can be outlined. Within the field of FWE nexus, practical experiments that link an established future vision with action, are developments of real-life alternative ways of thinking into the sustainability outcomes. Hoff et al. (2019); Vreugdenhil et al. (2012) discussed that practical experiments require an open and inclusive governance context in order to provide feedback and innovations to the policy. Several nexus studies have conducted experiments in real-life contexts involving multiple stakeholders. For instance, Siegner (2018) offers experiments in educational contexts such as students gardening for placing resources sustainability at the forefront of human consciousness.

In order to initiate a sustainability transition, experiments have to be incorporated into stakeholders' behavior (Nevens et al., 2013). In

that way, a learning perspective is needed. The lessons learned from envisioning efforts and practical experiments feed social capacity as well as the structure of knowledge for actions. Several studies enriched open and inclusive engagement of stakeholders within the nexus applications through learning. Agusdinata and Lukosch (2019) proposed gaming as a promising way to increase awareness of households about environmental issues and influence their behavior towards more sustainable practices.

The above-described purposes of the transdisciplinary nexus research have been covered by various practical schemes: information sharing, consultation, consensus building, decision-making, and partnership. These schemes identify the extent to which stakeholders are involved in the FWE nexus processes. Nexus research needs to know how and to what extent stakeholders are involved in the process (Stein et al., 2018). Stakeholders can potentially be involved in any of the three research purposes and their related schemes, although it is rare that they are involved in all. Fig. 4 presents dominant methods used for

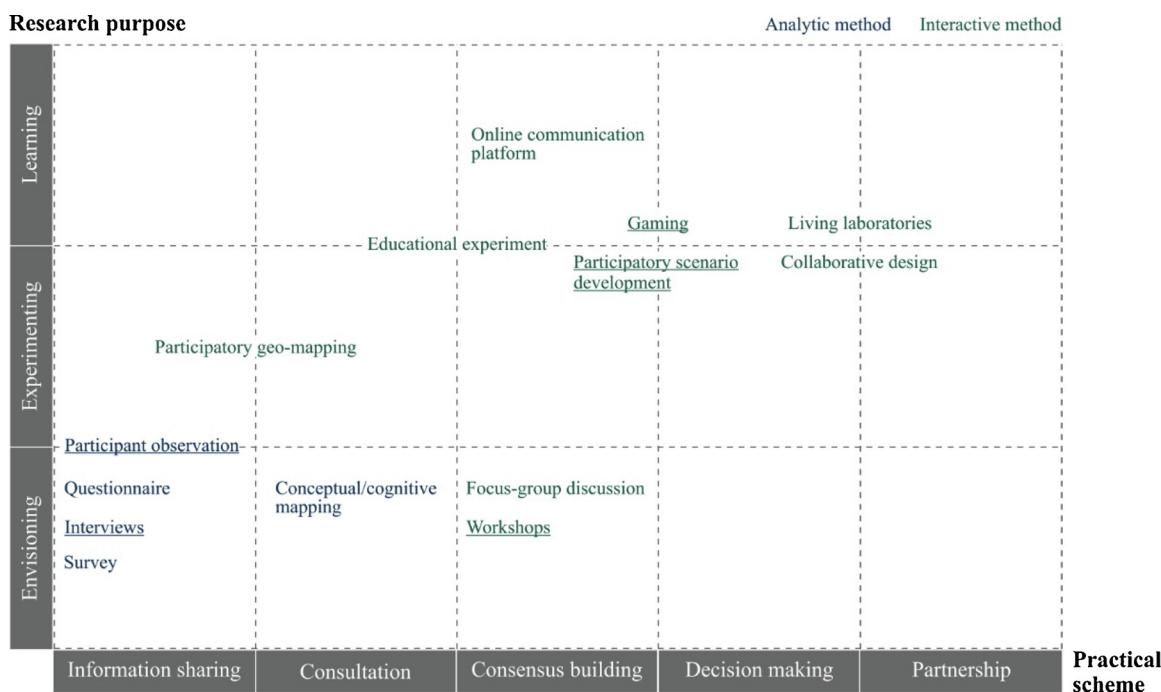


Fig. 4. Comparison of methods for the transdisciplinary FWE nexus. This comparison illustrates how multiple stakeholder engagement within nexus research and practice have been carried out. Used methods have different functionalities given the extent to which stakeholders are going to be involved in the process and the purpose of their involvement. The blue and green colors distinguish whether a method tends to be ‘analytic’ or ‘interactive’ in practice. The analytic term refers to a category of methods that involve a specific group of stakeholders to operate a specific shared activity. By contrast, interactive methods engage stakeholders in their implementation process in order to elicit the influence of variant values and commitments (adapted from [Stirling \(2015\)](#)). The underlined methods have been used most frequently by the transdisciplinary nexus research.

engaging multiple stakeholders within the FWE nexus research and practice. The methods used have different functionalities given the extent to which stakeholders are going to be involved in the process and the purpose of their involvement. Adapting from Stirling (2015), we grouped the methods into two categories: ‘analytic’ or ‘interactive.’ Analytic methods involve a specific group of stakeholders to operate a specific shared activity. By contrast, interactive methods engage stakeholders in the process of implementing those methods in order to elicit the influences of variant values and commitments.

From the review, it is evident that interviews, workshops, participant observation, participatory scenario development, and gaming are respectively (from the highest to the lowest order) the most frequently used methods within the transdisciplinary nexus research.

3.3.1. Interviews

Interviews are one-on-one (in person or phone) conversations where several questions are put to pre-defined people. The FWE nexus research has adopted interviews in order to collect context-specific data about socio-ecological status quo of an environmentally challenging area for likely improvements. Some research discusses interviews for identifying stakeholders (e.g., [White et al., 2017](#)), some for setting intervention goals (e.g., [Siegnar, 2018](#)), and several for identifying barriers to the implementation in practice (e.g., [Bréthaut et al., 2019](#); [Hoolahan, Larkin, et al., 2018](#); [Pardoe et al., 2018](#)). All these efforts let stakeholders get involved in envisioning the future of their living or working area and its potential development plans.

3.3.2. Workshops

Workshops design an interactive and inclusive environment where several people can reach a consensus on what their future decision regarding a specific subject should be. The use of workshops has supported the FWE nexus in bringing together multiple stakeholders with an equal chance of incorporation and integrating ideas. Hoolahan, Soutar et al. (2018); Treemore-Spears et al. (2016); Ziv et al. (2018)

fostered integrative nexus brainstorming and envisioning through active stakeholder participation and a convergent idea space. During the workshops, participants from various groups (e.g., academia, institutions, policymakers) were asked to generate as many ideas as possible for preferred pathways towards sustainable resources management and prioritize important ones together. Moreover, pointing out the need for constructive dialogue between nexus stakeholders, [Kumazawa et al. \(2017\)](#); [Yan and Roggema \(2019\)](#) proposed experimental workshops. They provided a space for multiple stakeholders to actively challenge each other's view through creating connections between their ideas and related features in real-world.

3.3.3. Participant observation

Participant observation is a qualitative data collection method that helps researchers become known to individual behaviors and their activities. Given the importance of human behavior towards the use, storage, and conservation of natural food, water, and energy resources, several FWE nexus research have adopted the participant observation method. Siegner (2018) adapted the participant observation method, over six weeks, to capture the effectiveness of experimental learning strategies on students' behavior towards climate change and natural resources security. From her findings, the participant observation method affords opportunities for understanding informal interactions among nexus stakeholders, their behavioral norms, and all related variables of interest for understanding the interrelated socio-ecological performances. Moreover, Yung et al. (2019) explored the LIVES Cambodia project, which adopted the participant observation method for understanding uncertainties to stakeholder engagement within the FWE nexus performances. The participant observation method supported this project with knowledge of how stakeholders change their thinking in decision-making processes.

3.3.4. Gaming

Games can provide an effective space in which stakeholders can

Table 1

A critical review of challenges to practical experiences of the transdisciplinary FWE nexus, in terms of inclusive stakeholder engagement, and their influences on potential sustainability outcomes.

The potential contribution of inclusive stakeholder engagement to the FWE nexus sustainability	Challenges to the inclusive nexus stakeholder engagement
Higher levels of communication enhance the <i>capability</i> of different planning horizons. Daher et al. (2019)	The <i>quality of communications</i> . Daher et al. (2019)
Transdisciplinarity enables <i>inclusive stakeholder dialogue</i> at multiple spatial levels. Mohtar and Daher (2019)	The need for a <i>large amount of data</i> at multiple spatial levels. Givens et al. (2018)
A higher level of cooperation among multiple spatial scales helps to <i>maximize the benefits and minimize the costs</i> associated with the three FWE resources. Basheer et al. (2018)	The requirement of <i>extensive temporal and human resources</i> in bringing together individuals with different experiences. Sušnjić et al. (2018)
Transdisciplinarity contributes to <i>raising awareness</i> and <i>building consensus</i> among stakeholders. Martinez et al. (2018)	<i>Timely decision-making process</i> . Howarth and Monasterolo (2017)
Multi-stakeholder engagement ensures that benefits and costs across FWE nexus are <i>socially and environmentally acceptable</i> . Matthews and McCartney (2018)	<i>Coordination of information flows</i> between actors at different scales. Karpouzoglou et al. (2017)
Group discussion helps to <i>build social capital</i> between scientists and other stakeholders. White et al. (2017)	Complexities in <i>direct coordination</i> between scientists that developed the nexus concepts and the broader stakeholder community. Bergendahl et al. (2018)
Knowledge co-production increases <i>transparency</i> and <i>trust</i> among key nexus actors. Webb et al. (2018)	Identification of stakeholders and the way to avoid <i>undesired dynamics</i> . Halbe et al. (2015)
Transdisciplinary policy-making <i>matches social scale with natural set up</i> . Spiegelberg et al. (2017)	<i>Varying level of knowledge</i> and <i>interest conflicts</i> . Heitmann et al. (2019)
Participatory scenario building enables decisionmakers to <i>achieve more sustainable and equitable options</i> addressing resource allocation. Johnson and Karlberg (2017)	<i>A deal of time</i> to understand the constructed scenario building platform. Kumazawa et al. (2017)
Cross-sectoral collaboration may result in <i>policy coherence</i> . Pardoe et al. (2018)	Incompatibility of <i>institutional structures</i> and factors of political economy. Pardoe et al. (2018)

exchange knowledge, increase their awareness, and learn skills. It is important for the FWE nexus that stakeholders acquire necessary skills for deliberative and pluralist policy making (Keshwani et al., 2017; Mochizuki et al., 2018). There are several gaming experiments in the FWE nexus that involved various groups of stakeholders and explored multiple alternative solutions to complex resource management issues. Serious games and role-playing games are the most frequent gaming types used by the FWE nexus research through which players play the role of different stakeholders and address their interests. Agusdinata and Lukosch (2019) explored the effects of a role-playing game on households' behavior towards FWE resource consumption. They figured out that a gaming experience can connect its participants to the real context by building a shared narrative, providing learning opportunities, and encouraging problem-solving. In addition, Mochizuki et al. (2018) discussed several serious gaming experiments in the FWE nexus. Their finding highlighted the role of gaming in teaching nexus stakeholders to apply systemic thinking to making collective decisions and actions.

3.3.5. Participatory scenario development

Participatory scenario development is a method for exploring with stakeholders various alternative storylines for the future (Voinov et al., 2016). The FWE nexus have adopted the participatory scenario development method extensively. The process of scenario development with multiple stakeholders supports the re-framing of nexus decision contexts towards more socially inclusive resource management (Colloff et al., 2019). For instance, Johnson and Karlberg (2017) explored the effect of such a participatory method on facilitating dialogue among nexus stakeholders with various levels of knowledge, experience, and interests. They emphasized the importance of local knowledge for a deep understanding of the FWE nexus issues in a particular context. Through their experience, stakeholders shared their local knowledge, and based on that, co-developed potential solutions for the future management of natural resources in Ethiopia.

3.4. Empirical evidence of the FWE nexus for transdisciplinarity

The transdisciplinary FWE nexus is more likely to succeed if active collaborations have happened among all groups of stakeholders

including scientists, politics, industrials, and communities (Bergendahl et al., 2018). Inclusive stakeholder engagement is essential to create actionable information (Bierbaum et al., 2013; Kraftl et al., 2019). This engagement should be inclusive, frequent, two-way, and integrated across different development stages in order to support iteratively co-produced information (Ernst and Preston, 2017; Lemos et al., 2012; Liu et al., 2008). Although multiple stakeholder engagement has long been the subject of FWE nexus debates, research has experienced difficulties at higher levels of collaboration in practice.

There are several limitations to the transdisciplinary nexus methods in real-world practical applications. Our review reveals these limitations as being context-, process-, or data-related constraints. This system of classification allows for the potential mixed adoption of various methods each addressing (a) specific limitation(s) (Hoolohan, Larkin, et al., 2018). The context-related limitations refer to the quality of communication (Daher et al., 2019; Halbe et al., 2015; Ziv et al., 2018), complexities in direct coordination among experts and non-experts (Bergendahl et al., 2018; Mochizuki et al., 2018), varying levels of knowledge among stakeholders (Johnson and Karlberg, 2017), and context-sensitivity of transdisciplinary approaches to the FWE nexus performances (de Strasser et al., 2016; Howarth and Monasterolo, 2016). Given the process of the transdisciplinary FWE nexus, experiments have faced constraints in accordance with the timely decision-and policy-making process in a socially inclusive approach (Howarth and Monasterolo, 2017; Kumazawa et al., 2017). Moreover, incompatibility of data and variability in data availability across various groups of stakeholders are some data-related limitations to the transdisciplinary FWE nexus research (Basheer et al., 2018; Givens et al., 2018; Mohtar and Daher, 2019; Xue et al., 2018).

Table 1 presents the extent to which these challenges influence the potential outcomes of the interlinked FWE nexus and sustainable development.

Together these results provide important insights into principle concerns for conducting transdisciplinary research on the FWE nexus and potential innovations in practice for sustainability achievements.

4. Discussion

We have shown the underlying scientific trend in adopting

transdisciplinarity towards linking FWE nexus applications and sustainable development. Research has shaped the transdisciplinary FWE nexus by competing interpretations. Some researchers perceive this concept as a driving cause for the legitimacy of policies and development plans, while some draw on its participative management perspective and the potential for stakeholders' empowerment. The variation of interpretations highlights that the transdisciplinary FWE nexus is not uniform. It requires knowledge of navigating social transformation to shape collective behaviors and constructive dialogue among stakeholders (Mochizuki et al., 2018).

The nexus scholar mindset has recently experienced a slight shift towards social inclusion and the likely subsequent active collaboration among various stakeholders. From the environmental nexus perspective, social inclusion is the process of improving a community's opportunity to contribute to shaping climate-resilient development and gain new adaptive skills (Bergendahl et al., 2018). The social relations and dense connectivity among stakeholders can reduce transition costs that may impede the effective governance of resources.

Nexus research has been able to partly accomplish the desired transition towards resources governance and sustainable development through methods of transdisciplinary integration (given Fig. 1). In this regard, communities as the end-users of the natural resources need to be aware of the issues, be able to adjust to environmental changes, and have the willingness to take improvement responsibilities (Blake et al., 2018). Raising community's awareness about the current socio-ecological challenges of their surrounding environment has been largely targeted by nexus debates (e.g., Agusdinata and Lukosch, 2019; Hannibal and Vedlitz, 2018; White et al., 2017). From the reviewed discourse and the structure of methods that have been used in this regard (e.g., field survey, questionnaire, and interviews), it is unlikely to observe active cooperation among nexus stakeholders as a result of such awareness-raising practices. However, these practices are prerequisites to building the capacity of nexus stakeholders to adjust to possible environmental changes (Mohtar and Lawford, 2016). Learning-based practices provide higher levels of communication among nexus stakeholders and subsequently allow them to consult each other about the issue and build consensus on potential solutions (Bierbaum et al., 2013). Learning-based methods such as educational experiments have contributed largely to enhance the ability of communities to adjust to environmental changes (Lotz-Sisitka et al., 2016).

Moreover, communities should take responsibility for sustainably developing their surrounding environment and making collective decisions for improvements. Nexus research has recently focused on the involvement of communities in decision-making processes. Gaming and participatory scenario development are such methods that nexus research has adopted in order to involve communities in decision-making processes and provide them with a sense of partnership. However, all these achievements are nascent and require more investigation to sustain practical defects.

Research has underlined the need for a balanced governance structure that incentivizes stakeholders' communication in practice and facilitates the collaborative development of new solutions. A particular impediment to this lies in unequal power relations and the structure of privilege within and between different groups of stakeholders (Stirling, 2015). The effective adoption of transdisciplinary nexus-related methods depends on nurturing capabilities that resist such inequalities. In addition, challenges of the FWE nexus are themselves created by diversities of natural settings, institutional sectors, and interests. Therefore, addressing these challenges requires relational diversities in methods and capabilities. However, as has been illustrated by the reviewed literature, there exists no unique way to express these various kinds of diversity. Nexus practices lie grounded in the specific context of research, particular disciplines, and stakeholders.

A further required capability is due caution in the contextualization of actions and the implications of generalization (Grafton et al., 2016; Lawford, 2019; Mohtar and Daher, 2019). Following statements present

recommendations to achieve successful nexus results in practice.

- The transdisciplinary process should be *balanced* in the sense of not giving too much power to one particular group of stakeholders over others even if that group leads the process. To do so, all groups of stakeholders should get involved from the very beginning of the process until the end. It may require research to employ multiple methods, for both envisioning and doing by learning, in order to realize equal contribution of stakeholders and their collective responsibilities. In case of achieving successful results in balancing power relations among nexus stakeholders, potential sustainability outcomes 'cooperative interactions' and 'adaptive capacity' would happen.
- The groups of transdisciplinary nexus stakeholders should be *representative* to generate true sharing of knowledge and allow stakeholders to challenge different opinions. It is important to get all relevant sectors and individuals around the table and let them learn from each other. The inclusive selection of stakeholders for nexus practices requires direct observation. It enables the involvement of voices from different groups of stakeholders (e.g., residents, local environmental managers, development companies, and so forth) and subsequently would lead to 'context-specific (localized) interventions.'
- The offer of the transdisciplinary perspective on the FWE nexus process should be *timely*. Stakeholders' communication should start early at the beginning of the process. Specifically, the timely involvement of local stakeholders may be more satisfying than a sudden immersion in highly structured discussion meetings. If all stakeholders get involved at the same time, at the same level, and with equal power, 'efficient solutions' would be offered timely.
- The transdisciplinary nexus process should avoid *marginalizing* any stakeholder. It should be ensured that all involved stakeholders express an opinion. In many cases, the role of communities in nexus projects is limited to providing local information. Securing their active engagement is essential to understanding and adjusting the way nexus practices should be taken. It would develop a new 'resilient alliance' among nexus stakeholders in response to environmental changes.
- The collaboration sessions should take place in *locations with no connotations*. It has been widely seen that collaboration sessions of nexus projects are held at universities, city council offices, or management companies that could have certain bias and may alter the development of the process. Public spaces like libraries that are open to every city actor may make a sense of ownership for less powerful stakeholders (e.g., local communities). Having a sense of ownership would then foster flows of comprehensive knowledge among stakeholders.

The interlinkages among transdisciplinarity, FWE nexus, and sustainable development shows that a consensus on political expectations is required. Policy-makers need a clear elaboration of role distribution across actors, the currently implemented governance structure, and the measurement of actions in real contexts. A detailed understanding of these factors then supports optimal, acceptable, and implementable policies.

5. Concluding remarks

FWE nexus can potentially support the integrated accomplishment of sustainable development goals if a transdisciplinary approach is taken. The existing literature on the FWE nexus shows that soaring research interests have been directed towards understanding, identifying, and qualifying the interrelationships among diverse stakeholders to inclusively involve nexus actors in the process and identify governance solutions. Although the underlying ideas of transdisciplinary nexus thinking have been widely accepted, there is no strong view of

the understanding of its potentials and limits to practice. Concerning the varied interpretations of links between FWE nexus, sustainable development, and transdisciplinarity, we proposed a framework of transdisciplinary nexus conceptualization. We also believe that the future conceptual development of this framework can further explore its key factors and the way they interact in different contexts.

Methods pertaining to transdisciplinary nexus applications are still needed to realize inclusive, active, and equal collaborative management. Future transdisciplinary nexus research should be directed towards the co-production of knowledge, cross-region communication mechanisms, co-development of decision, and governance transition. Extensive endeavors should be made to identify the key determinants of stakeholders' interactions, feasible communications, and procedures for advanced cooperative practices through real-world applications. However, the governance regimes, with a high level of context-dependency, make transdisciplinary nexus thinking difficult to enhance in a short time. Thus, nexus research should envisage likely circumstances in future.

Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.envsci.2019.09.003>.

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