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Review

Deciphering the scientific literature on SDG interactions: A review and reading guide

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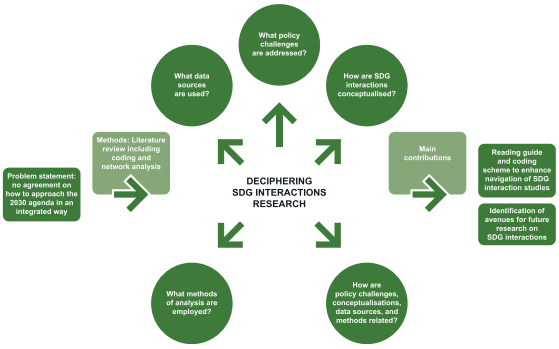
HIGHLIGHTS

- An integrated understanding of the 2030 Agenda is key to successful implementation.
- Currently there is no agreement on how to support policy-relevant integration.
- A review, and a network analysis, of 70 scientific articles were conducted.
- Approaches to integration, and policy challenges these address, were identified.
- A guide to make the literature more broadly accessible and comparable is proposed.

GRAPHICAL ABSTRACT



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ABSTRACT

The 2030 Agenda includes 17 overarching Sustainable Development Goals (SDGs). These are integrated in nature, and a principle of indivisibility should guide their implementation. Yet, the 2030 Agenda itself does not provide guidance on what indivisibility means in practice, how the SDGs interact, or on how to assess these interactions. The fast-emerging field of what could be referred to as SDG interaction studies seeks to provide such guidance, but as of yet there is no general agreement on what it means to take an integrated approach to the SDGs. Hence, navigating the diverse research landscape on SDG interactions might prove challenging. This paper aims to decipher the literature on SDG interactions by providing an overview of the current research, based on a sample of 70 peer-reviewed articles. The review explores four themes in SDG interaction research by mapping: (i) policy challenges typically addressed, (ii) ways in which SDG 'interactions' have been conceptualized, (iii) data sources used, and (iv) methods of analysis frequently employed. Research gaps are identified, where perspectives largely missing include policy innovation, and integrated monitoring and evaluation. Further, few studies consider actor interactions, account for geographic spill-overs, analyze SDG indicator interactions, employ participatory methods, or take a whole-systems approach to the 2030 Agenda. Failing to address these gaps could lead to inefficient SDG implementation and delay goal attainment. Another contribution of the paper is a reading guide, proposing a way to decipher the literature along the themes emerging from the review, and offering a structure to code future papers.

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1. Introduction

The 2030 Agenda was adopted by the United Nations General Assembly in September 2015, presenting an ambitious vision of transformative change towards reaching a more sustainable future by the year 2030 (UN, 2015). The 2030 Agenda includes 17 overarching sustainable development goals (SDGs), 169 related targets and more than 230 indicators for monitoring their progress. Central to the 2030 Agenda, and a distinguishing feature as compared to other sustainability initiatives, is that it is intended to be treated as universal and indivisible. Universality implies that the 2030 Agenda applies to all nations and actors around the globe, regardless of current level of income or sustainability challenges. The principle of indivisibility means that the implementation of the 2030 Agenda should be based on integrated approaches rather than on siloed knowledge and policy-making. While both these principles are key to the 2030 Agenda, the present paper focuses specifically on the principle of indivisibility and the challenges linked to understanding how the SDGs interact. This, as although the formulation of the 2030 Agenda stresses that it should be treated as a unified whole, it does not specify what interactions that exist between the SDGs, the nature of these interactions, or what they imply for policy- and decision making. It also does not provide guidance on how to identify or address potential spill-over effects and cross-scale interactions. (Elder et al., 2016; Nilsson et al., 2018)

Against this background, the scientific community could play a vital role in supporting SDG implementation by strengthening the knowledge base on SDG interactions, thereby enabling evidence-based decision-making. Since the adoption of the 2030 Agenda, the number of studies aiming to create an integrated understanding of the SDGs has been growing rapidly. However, in the fast-emerging field of what could be referred to as SDG interaction studies, there is no general agreement on what defines an integrated approach, or on how science can best approach SDG interactions in policy-relevant ways. The principle of indivisibility is understood and addressed in different ways, and the interested reader trying to navigate the diverse research landscape on SDG interactions will face challenges. While the recognition of the indivisible nature of the SDGs is critical to goal attainment, supporting integrated policy-making in practice requires clarity and overview of what different analytical approaches bring towards this end.

Few studies have previously aimed to provide an overview of the scientific literature on SDG interactions. Breuer et al. (2019) review existing frameworks developed to conceptualize SDG interactions. Their study focuses specifically on methodological strengths and weaknesses, and on how the identified frameworks can help form coherent policy strategies for the SDGs. Most of the literature included in the review was collected in an early stage of SDG implementation, encompassing in total nine studies, all published in 2017 (Breuer et al., 2019). Allen et al. (2018a) review academic and grey literature on SDG implementation, and contrast it with national experiences of the implementation process. They specifically asses how approaches and advice provided by the expert literature are translated into practice in national implementation. They find that even though there has been progress in early planning stages, there is still a lack of knowledge on SDG interactions, trade-offs, and synergies between targets. The authors stress that a lack of systems thinking and integrated assessments may hinder the effective implementation of the SDGs (Allen et al., 2018a). In our research we have not come across additional examples of previous studies attempting to provide a more general overview of the scientific literature on SDG interactions and what it offers. In view of this, the present paper aims to decipher the literature on SDG interactions, by providing an overview and structure of the current research landscape.

The study departed from the following overarching questions:

- How has the indivisible nature of the 2030 Agenda been approached?
- How do the different approaches to SDG interactions co-occur, complement each other, or leave analytical gaps?

The remaining part of the paper is structured as follows. First, we provide an overview of our research design and process. Second, we present the findings along four themes of specific importance that emerged from the literature review, illustrating typical (i) Policy challenges, (ii) Interaction conceptualizations, (iii) Data sources, and (iv) Methods of analysis employed in the field, as well as how these relate to each other. Finally, we discuss implications of these findings, present a reading guide for SDG interaction studies and comment on its hoped-for contribution, and highlight research gaps and potential future research avenues.

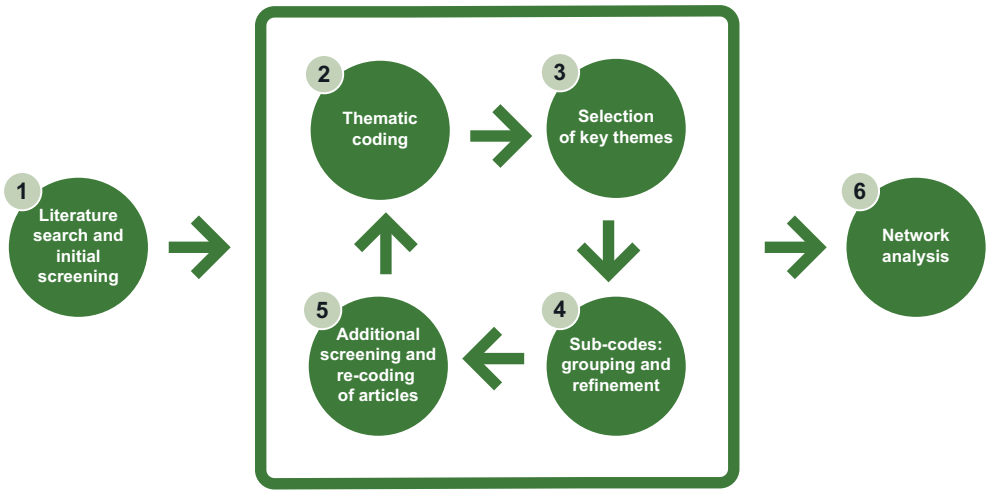

Fig. 1. Overview of the research process.

2. Methods

The present paper is based on a scoping review of the literature addressing SDG interactions. The SDG interactions field is relatively young but rapidly growing, starting to form in relation to the adoption of the 2030 Agenda in 2015. The research process consisted of six steps, where iterative rounds of literature sampling, coding, and analysis were carried out, as described in Fig. 1. The review may serve as a basis for meta-analysis or as input to a systematic review.

2.1. Review of the scientific literature

The first step of the research process consisted of a literature search and initial screening, using the SCOPUS electronic database. Also, key experts and researchers in the field of SDG interactions were consulted. The search strings for the scientific article database were: "Sustainable Development Goals" AND "systems analysis"/"interactions"/"system dynamics"/"network analysis"/"interlinkages." The keywords were chosen on the basis that they are broad enough to capture a diverse set of approaches to SDG interactions. However, the initial search strings could bias the sample towards specific methods (e.g., network analysis) or exclude studies using closely related terms such as interconnected or integrated. To address this, we employed a snowballing approach, made a scanning of reference lists, and conducted additional searches in the scientific article databases, to ensure wider coverage. However, our sample is not aiming to be exhaustive. Last, a screening of grey literature (i.e., scientific information published in sources other than scientific journals, including reports, manuscripts, and online tools databases and guidelines) was carried out. This screening was primarily intended to enhance our understanding of the field. Only peer-reviewed scientific articles were included in the coding and network analysis.

The inclusion criteria for the scientific articles were:

a) The application or approach presented in the article must address the SDGs. This criterion was understood in a broad sense, including

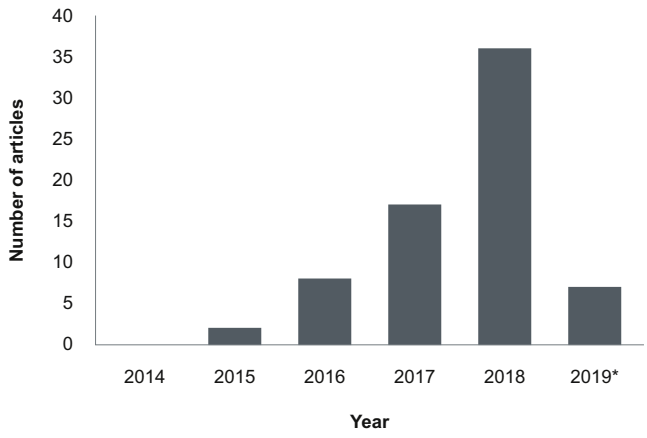

Fig. 2. Number of articles published per year. *The cut-off date for the sampling of literature was at the beginning of April 2019.

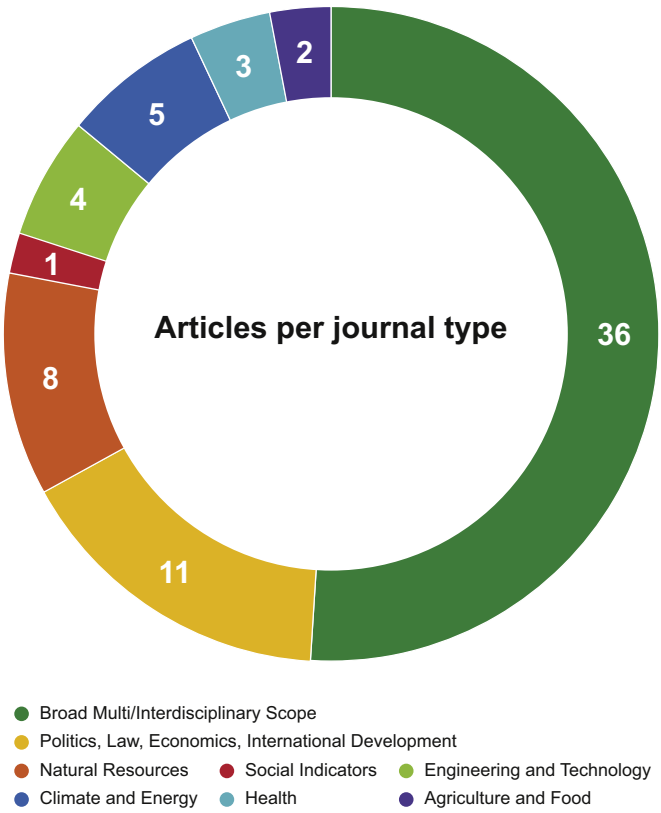

Fig. 3. Articles per journal type (thematic focus).

studies with the stated objective to better understand, interpret, critically examine, or support the implementation of the SDGs.

b) The article needed to take an integrated approach to the SDGs. This could be stated explicitly in the paper, or be inferred by the use of terms such as "trade-offs," "synergies," or "policy coherence across interconnected goals." Thus, the included articles present a mapping or analysis of SDG interactions of some sort.

Throughout the research process the literature sample list was refined and some articles excluded, resulting in a final sample of 70 articles. All articles included in the review were published between 2015 and early 2019 (Fig. 2). The articles are found in 46 different journals, a majority out of which has a broad multi/interdisciplinary scope (Fig. 3). For a complete overview of the sampled literature, see Appendix A.

2.2. Data analysis

The subsequent five steps of data analysis were carried out in iterative rounds. The initial thematic coding was based on a number of guiding questions (Table 1). The guiding questions represent overarching themes relevant to creating a better understanding of the field of SDG interaction studies, such as what aims (research or policy-related), audience, scales, contexts, and methods that are commonly found in the SDG interactions literature. From the initial list of questions in Table 1, four themes were singled out and analyzed in further depth: Policy challenges (guiding question 3), Interaction conceptualizations (guiding question 8), Data sources (guiding question 7), and Methods of analysis (guiding question 5). These themes were chosen as they provide an understanding of how SDG interactions may be identified and analyzed. They also seek to identify how the knowledge generated is intended to inform policy-making. Thereafter, sub-codes were identified under each overarching theme. In an iterative process the sub-codes were refined and grouped, and the literature re-coded accordingly. The structuring and analysis of the articles were carried out using Excel and the MAXQDA[1] software. For a complete list of themes, sub-codes and articles, see Appendix B.

In order to analyze how the different themes and the associated sub-codes relate to each other we used techniques from network analysis. As a basis for the analysis we constructed a network with sub-codes defining the nodes and articles defining the links in-between them: If article 1 is coded *A, B* and *C* and article 2 is coded *A, C* and *D* there exists links of weight 1 between sub-codes *A* and *B, B* and *C, A* and *D, C* and *D,* and a link of strength 2 between sub-codes *A* and *C*. This is a so-called co-occurrence network, i.e., a network describing how sub-codes relate to each other based on how they occur in the reviewed articles. In this network, the links are unevenly distributed and therefore the sub-codes are divided into clusters of higher concentrations of links within those clusters. There is no universally accepted quantitative definition of how a network should be divided into clusters. Here we use a modularity-based approach to clustering (Newman and Girvan, 2004; Newman, 2006). The intuition behind modularity – that a good division of the nodes into clusters is one in which there are fewer links between the clusters than what is statistically expected – is appropriate for our analysis. When depicting clustered networks a dedicated mapping technique needs to be employed. In bibliometric research a combination of mapping and clustering techniques is often used in order to study and visualize, for example, collaboration patterns in a scientific domain (Waltman et al., 2010). We used the software tool VOSviewer[2] for operationalizing a combination of a modularity-based approach to clustering and mapping for visualization.

Table 1
Guiding questions for coding.

Guiding question	Explanation
1. What approach to SDG interactions is presented in the study?	Brief description of the study.
2. What is the overarching knowledge gap the study is aiming to address?	Specification of the general question, challenge, or knowledge gap the approach is trying to address, based on the problem formulation/research question(s).
3. What is the policy challenge the study is aiming to address?	Specification of the policy-relevant questions that may be addressed using the approach presented in the study, and to what policy needs the approach responds.
4. In what stages of the 2030 Agenda implementation could it be useful?	Specification of where in the policy cycle the approach may be used, for example in the policy design, implementation, or follow-up stage?
5. What methods are used?	Identification of the method or combination of methods used, and whether the approach is aiming to provide a tool for decision-makers or not.
6. How is the approach carried out?	Description of practical and analytical steps.
7. What sources of data are used in the study?	Identification of the data sources (links closely to the methods question).
8. How does the approach deal with SDG interactions?	Broad reaching question, aiming to explore how SDG interactions are understood and how they are addressed analytically in each study.
9. What is the intended user group of the study?	Identification of the target audience for the results, as well as to whom the approach might be useful.
10. In what context, and at what scale, is the approach applied?	Description of the scale of analysis and context in which the approach has been tested/used.
11. What are the strengths of the approach, in the context of the implementation of the 2030 Agenda?	Suggested strengths of the approach, based on what is presented in the article.
12. What are the weaknesses of the approach, in the context of the implementation of the 2030 Agenda?	Suggested weaknesses of the approach, based on what is presented in the article.
13. Are there planned extensions or further developments ahead, or any additional recommendations for future work?	Description of already planned extensions of the approach, or more general suggestions for future work provided in the article.

3. Results

The results are presented along the chosen four themes, followed by the co-occurrence network. The first theme focuses on policy challenges. These policy challenges are the underlying rationale for the study of SDG interactions, making explicit the needs to which the scientific community responds. The second theme focuses on how SDG interactions are conceptualized in the literature, clarifying what can be learned about the nature of these interactions. The third theme addresses the data sources used to underpin the existence of these interactions, and the fourth theme the methods of data analysis. For each theme, the sub-codes have been translated into guiding questions, making up the basis for the reading guide (Box 1–5 in the following sections).

3.1. The policy challenges addressed by SDG interaction studies

As the reviewed literature has the global policy process of the 2030 Agenda as focus, clarity on what policy challenges the studies seek to address can be expected. However, this seems not always to be the case. Many studies remain vague in what policy challenge their research addresses, either because their objective is not to directly inform policy or because they fail to clearly express their contributions. Yet, we derive six policy challenges that are often in focus in the SDG interactions literature. An overview of the frequency of occurrence of these policy challenges in the reviewed articles is found in Fig. 4, while Box 1 links each policy challenge to questions for the reading guide.

[1] The MAXQDA software is available for download at: https://www.maxqda.com
[2] Can be accessed online at: www.vosviewer.com

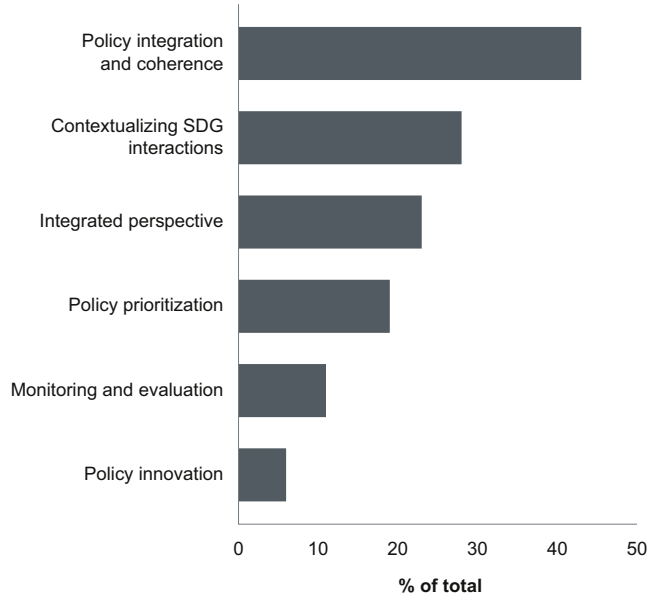

Fig. 4. Policy challenges commonly addressed in the reviewed literature (sub-codes as they occur in a percentage of the total sample).

First, being concerned with SDG interactions, most reviewed articles have at least an implicit objective to enhance **policy integration and coherence (P1).** The motivating assumption is that integrated and coherent policies can optimize resource use and generate more sustainable outcomes, by avoiding counteracting objectives and incentives. One group of papers focuses specifically on the challenges of *realizing* policy coherence; they explore questions of institutional barriers to integrated policy-making, how more integrated approaches can be implemented in practice, and how synergies can be maximized or trade-offs avoided as new policy is being formulated. For example, it has been demonstrated how systems analyses allow policy-makers to negotiate trade-offs and exploit synergies as they formulate SDG strategies, supporting the identification of coherent policy (Obersteiner et al., 2016). Dynamic simulation models have been put forward as facilitators of a shift to discussions on development that is grounded in systems thinking (Collste et al., 2017), and mapping of SDG interactions has been suggested as a way to help policy-makers and researchers find development pathways that minimize negative interactions while enhancing positive ones (Nilsson et al., 2018). Other studies focus on how cross-sector planning and decision-making can be encouraged and enhanced, stating that a greater focus on the interlinkages and synergies among goals could enhance the effectiveness of implementation and reduce costs. However, enhanced governance and coordination capacity are required (Yillia, 2016; Elder et al., 2016). Along the same lines, it has been emphasized that a shift to integrated approaches requires pro-active engagement and enhanced coordination across government departments and scales (McCollum et al., 2018). Several studies addressing the first policy challenge of enhanced policy integration and coherence also provide insights on *how* all or a subset of SDGs interact. Thus, they provide information on policy conflicts and synergies as a means to strengthen the coherence of policies (rather than on the barriers or opportunities for policy-makers to take them into consideration). They are yet included in this category as their overarching objective is to support more coherent policy (see e.g., Maes et al. (2019), Blanchard et al. (2017) and Chakraborty et al. (2018)).

Box 1
Reading guide: The policy challenges.

Six policy challenges are typically addressed by SDG interaction studies. When approaching an SDG interaction study, the following guiding questions can be used to map what policy challenge it responds to:

1. Policy integration and coherence
   Guiding question: Does the study have an explicit objective to enhance policy integration and coherence?
2. Policy innovation
   Guiding question: Does the study suggest new policy measures or new uses of existing policy instruments?
3. Contextualizing SDG interactions
   Guiding question: Does the study analyze interactions at lower scale(s) than the global?
4. Policy prioritization
   Guiding question: Does the study aim to provide guidance on, for example, what goals (targets/indicators), interventions, or actor collaborations to prioritize for maximizing SDG progress?
5. Integrated perspective
   Guiding question: Does the study aim to contribute to better stakeholder inclusion and learning, thereby building the capacity of stakeholders to take an integrated perspective?
6. Monitoring and evaluation
   Guiding question: Is the aim of the study to support monitoring of progress or evaluation of past policy interventions, addressing issues of accountability in integrated policy processes?

Second, a closely related policy challenge is that achieving the goals of the 2030 Agenda may require new policy approaches, policy instruments or new uses of existing policy instruments. In response, a number of studies have the stated objective of informing **policy innovation (P2)**. In contrast to the studies belonging to the first category, these studies focus on the output of policy-making, rather than on generating insights on how the process of policy-making can better support coherence. These papers question the outputs that traditional policy-making generates and aim to inform or identify new innovative policy measures and business models. For example, it has been suggested that deeper changes in existing strategies are needed to make the trade-offs between SDGs structurally non-obstructive (Pradhan et al., 2017), and that new business models based on systems thinking are needed, integrating environmental, social, and economic interests (Keesstra et al., 2018). Other studies assess alternative pathways for SDG achievement focused on lifestyle changes, decentralized governance and technology (Moyer and Bohl, 2019), or stress that rebounds (or problem shifting) across resources need to be addressed to ensure effective design of emerging policy paradigms such as the SDGs (Font Vivanco et al., 2018).

Third, while the 2030 Agenda is globally focused at the onset, priorities, needs, and the nature of SDG interactions are context specific. Actions in support of the 2030 Agenda are taking place primarily at the regional, national and local levels, and translating the global SDG framework to specific decision-making contexts therefore constitutes a critical policy challenge**.** Appropriately, one set of papers focuses on **contextualizing SDG interactions (P3)**. Studies have shown that the geographical level matters significantly in assessments of SDG achievement (Moyer and Bohl, 2019), and that realizing co-benefits among the SDGs is dependent on the context specific social-ecological dynamics and policy priorities (Singh et al., 2018). As concluded by McCollum et al. (2018) in the case of energy, knowledge gaps remain about how interactions play out in different contexts, and Nilsson et al. (2016) even warn against relying on generalized knowledge on SDG interactions because of how these interactions are influenced by differences in geography, governance and technology. A number of papers apply their analysis to specific contexts and contribute to building up the knowledge base at lower scales than the global. SDG interactions have

been explored in, for example, coastal Bangladesh (Hutton et al., 2018), Sweden (Weitz et al., 2017), in a number of countries in the Arab region (Allen et al., 2017), and at a sectorial level in Uruguay (Kanter et al., 2016). There are also examples of studies that contextualize SDG interactions in relation to other geographies (Hoff, 2018; Liu, 2017). They focus on how coherence can be achieved across geographical boundaries and account for externalities across different contexts, raising questions of fair allocations of resources, emissions and burden-sharing.

Fourth, multiple development pathways and associated policy may deliver similar outcomes, but might be more or less desirable to pursue due to contextual factors (e.g., political, ideological, technological, financial or geophysical). Moreover, certain policy outcomes may be prerequisites for other policies to succeed, and strategies need to be sequenced to support progress towards multiple goals at the same time. Identifying such hierarchies and thereby enabling **policy prioritization (P4)** constitutes a critical challenge in the SDG implementation process. One set of studies provides specific tools and processes to guide such priority-setting, either for all 17 SDGs and targets or for specific topics. For example, these studies present frameworks developed to guide priority setting (Singh et al., 2018; Weitz et al., 2017; Kumar et al., 2018), they rank synergies and trade-offs between SDGs at the global and country-level (Pradhan et al., 2017), and inform strategy development by studying different pathways for achieving long-term objectives and what they imply for short-term action (van Vuuren et al., 2015).

Fifth, for successful implementation of the 2030 Agenda, stakeholders from a broad range of sectors need to be included in the process. Here, strengthening the ability of stakeholders to take an **integrated perspective (P5)** is key. This is a challenge to most governments, used to operating in siloes. Thus, part of the challenge lies in creating decision spaces that give voice to a broad range of actors, and another in ensuring that this engagement promotes systemic thinking and learning. A number of papers seek to address this challenge. They call for or present new frameworks for strengthening stakeholder participation, for structuring knowledge for policy-makers (Yillia, 2016; Maes et al., 2019; McCollum et al., 2018), or for improving the uptake of interaction analysis outputs among policy-makers (Weitz et al., 2017). These studies also seek to find new ways to develop and communicate future scenarios, with a greater focus on human behavior and co-creation of decision-making frameworks (Hutton et al., 2018), which otherwise tend to rely on quantitative data and positivist approaches.

Finally, a related policy challenge is to ensure that those involved in decision-making processes can be held accountable. As a means for accountability, proper **monitoring and evaluation (P6)** of integrated policy interventions are needed. With a deeper understanding of interactions, as promoted by the set of papers focused on strengthening stakeholders' ability to take an integrated perspective, stakeholders can more easily engage in such mechanisms. So, while collectively the papers included in our review provide insights that strengthen opportunities for monitoring and evaluation (e.g., by clarifying linkages between the SDGs or by providing a systemic overview of progress), one set of papers focuses more directly on this issue. Studies have been exploring how accountability regimes and policy integration and coherence are potentially conflicting (Karlsson-Vinkhuyzen et al., 2018), frameworks for developing theory of transformation and indicators that can trace change in complex systems have been proposed and illustrated (Kopainsky et al., 2018), and challenges in measuring progress in integrated targets have been lifted (Le Blanc, 2015).

3.2. What defines "SDG interactions"? The conceptualizations

There are numerous ways in which SDG interactions have been conceptualized in the literature. Both in terms of *what entities* that are analyzed in these studies, and in terms of the information provided about *how* these entities interact. A higher awareness of the diversity in conceptualizations, and better distinguishing between the studied entities (the what) and the nature of these interactions (the how), can help the intended audience of SDG interaction studies put results into context. Further, it could guide policy-makers in identifying what studies that could be used as a basis for addressing a specific policy question.

3.2.1. Interaction entities – The what

When trying to understand how the indivisible nature of the 2030 Agenda has been approached and conceptualized, a starting question is in-between what a given study seeks to find interactions. Some studies set the research boundary so that the primary interest lies within the scope of the 2030 Agenda itself (in full or a subset of it). Other studies also include interactions across policy areas, themes, or system structures relevant to but outside of the Agenda's formulation. Each of these dimensions could be analyzed from an integrated perspective. Thus, what we here refer to as "interaction entities" are the objects which are potentially connected in an SDG interaction study; if X is connected to Y, then X and Y are the interaction entities. In different fields of systems analysis X and Y may be referred to using different terminologies, such as nodes in network analysis or variables in system dynamics.

This understanding of interaction entities emerged from the literature on SDG interactions. Naturally, a relatively large number of studies focus primarily on the goals, targets, or indicators of the 2030 Agenda itself. Some of these remain at the goal-level, analyzing **goal-goal interactions (C1).** Examples include studies of SDG 6 (clean water and sanitation) and potential interlinkages with other SDGs (Flörke et al., 2019), trade-offs between social, economic, and environmental SDGs (Hutton et al., 2018), or studies mapping interactions across all goals (Zhang et al., 2016). Other studies assess **target-target interactions (C2)**, for example in the context of water quality (Alcamo, 2019), the water-food-energy nexus (Fader et al., 2018), or energy interlinkages (Santika et al., 2019). There are also studies exploring **indicator-indicator interactions (C3)**, such as in analysis of trade-offs and synergies between indicator pairs (Pradhan et al., 2017). Moreover, some studies have linked the goals, targets or indicators to policy in a particular context and study **policy-policy interactions (C4)**. These studies cover, for example, rebound effects of resource efficiency policy (Font Vivanco et al., 2018) or synergy potential between climate change mitigation interventions and forest conservation policies (Matsumoto et al., 2018). Lastly, there are also studies of interactions across **goals, targets, indicators and/or policy (C5),** stressing the need for integration (Stafford-Smith et al., 2017)**,** providing analysis connecting economy, water, food and energy security issues (Mainali et al., 2018), or aiming to identify leverage points for change (Lim et al., 2018).

Common to all of the above is that they present analyses of interactions that are internal to the 2030 Agenda. However, as previously stated, there are several studies acknowledging that the goals, targets, and indicators do not exist in a vacuum by including **external entities (C6)** in the analysis. Studies that consider broader system structures explore interaction with drivers that govern change in the SDGs, e.g., different scenarios or policy clusters (Josephsen, 2017; Sharif and Irani, 2017; van Vuuren et al., 2015). Other examples include the study of interactions among international development goals for reducing inequality (SDG 10) (Glover et al., 2016), the study of how food production systems affect specific SDGs (Kopainsky et al., 2018), or how bio-economy goals (Heimann, 2018), ecosystem services (Wood et al., 2018), gender issues (Manandhar et al., 2018), smallholder forestry (De Jong et al., 2018), governance (Bowen et al., 2017) or the water-energy-food nexus (Liu et al., 2018) interact with the objectives outlined in the goals and targets of the 2030 Agenda.

Additionally, as previously mentioned, a small set of papers focuses on the **geographic location (C7)** of the interaction entities. These studies are concerned with how interactions connect countries or regions of different income levels, either adjacent or distant (Hoff, 2018; Liu, 2017; Liu et al., 2018; Stafford-Smith et al., 2017). Fig. 5 provides an overview

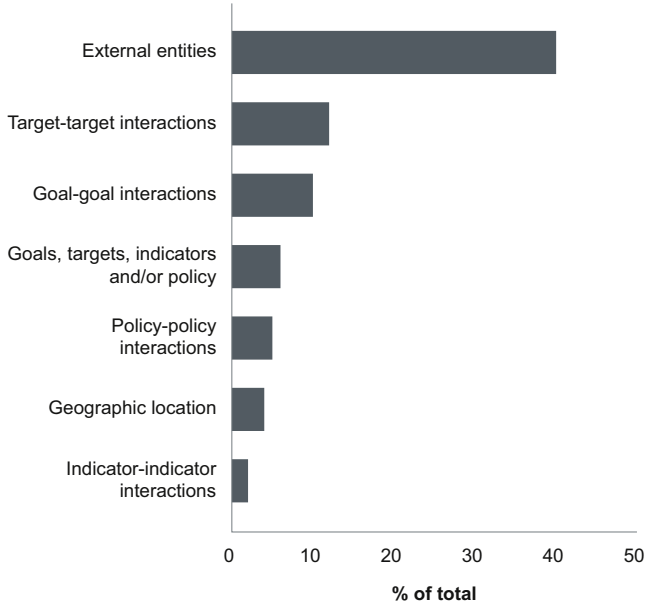

Fig. 5. Interaction entities typically analyzed in the reviewed literature (sub-codes as they occur in a percentage of the total sample).

of how frequently the sub-codes emerge in the literature sample, and Box 2 translates the interaction entities into guiding questions.

3.2.2. Interaction qualifiers – The how

Another analytical dimension emerging from the literature is what could be referred to as "interaction qualifiers." Interaction qualifiers can be understood as the information assigned to each link between two entities, and these qualifiers influence the type of analysis that can be performed. It is difficult to provide a measure of how frequently they occur based on the coding of the sampled literature. This as they oftentimes are not explicitly mentioned in the studies, but follow largely from the research question, the methods employed, and the availability of data. Box 3 summarizes and links the interaction qualifiers to guiding questions.

Moving beyond a statement that two interaction entities are somehow related, additional information about what characterizes the interaction could include stating which is the independent and dependent variable, or if the connection is multi-directional (Lim et al., 2018; Nilsson et al., 2016; Alcamo, 2019). Another example is assigning a polarity, which specifies if change in the independent variable causes the dependent variable to change in the same or opposite direction (Flörke et al., 2019). Other conceptual interaction qualifiers specify if the hypothesized interaction is causal (Dörgő et al., 2018; Collste et al., 2017) or a correlation (Pradhan et al., 2017). Moreover, while some studies focus only on the direct connection between the interaction entities, other consider chains of interactions or even the prevalence of circular connections, so-called feedback loops (Zhang et al., 2016). These can be reinforcing, thereby amplifying an initial change in a system, or balancing, thereby dampening system change.

Information about an interaction can also be linked to what it is made up of, e.g., flows of information or materials. Another type of descriptive information relates to the nature of influence, for example specifying if an interaction entity is shaping or modifying another interaction entity (Chakraborty et al., 2018). A qualifier could also specify what the impact of change in one interaction entity means for another entity, for example when the interaction entities are the SDGs themselves, and the guiding question is how progress on one goal affects the ability to progress on another goal (Weitz et al.,

Box 2
Reading guide: Interaction entities.

Seven types of interaction entities typically occur in SDG interaction studies. Identifying which category a study belongs to is helpful in clarifying the boundaries of what is being studied:

1. SDG goals (goal-goal interactions)
   Guiding question: Are the interacting entities the 17 SDGs, or a subset of them?
2. SDG targets (target-target interactions)
   Guiding question: Are the interacting entities the 169 targets of the SDGs, or a subset of them?
3. SDG indicators (indicator-indicator interactions)
   Guiding question: Are the interacting entities the official SDG indicators, or a subset of them?
4. SDG policy (policy-policy interactions)
   Guiding question: Are the interacting entities policy(ies) specifically intended to support implementation of the SDGs, or a subset of them?
5. SDG goal/target/indicator and/or policy interactions
   Guiding question: Are the interacting entities a mix of SDG goals/targets/indicators and/or policy, or a subset of them?
6. External entities
   Guiding question: Are the interacting entities one of the above SDG entities and an external entity (e.g., a theme, policy, policy cluster, scenario or driver of change) not explicitly covered by the 2030 Agenda?
7. Geographic location
   Guiding question: Are the geographies of the SDG interactions specified?

Box 3
Reading guide: Interaction qualifiers.

Eight different interaction qualifiers were identified in the reviewed literature, as summarized and translated into guiding questions below:

1. Minimum information: existence of an interaction
   Guiding question: Does the study provide no additional information than solely stating that an interaction exists?
2. Direction
   Guiding question: Does the study specify which is the independent and dependent interaction entity?
3. Polarity
   Guiding question: Does the study assign polarities?
4. Causality or correlation
   Guiding question: Is it clear if the study deals with causality or correlation?
5. Direct links, indirect links, feedbacks
   Guiding question: Does the study consider direct interactions, chains of interactions or circular connections (feedbacks)?
6. Other descriptive information
   Guiding question: Does the study use other descriptive labels or categories to describe the interactions?
7. Relative strengths
   Guiding question: Does the study provide some sort of indication of relative strength, e.g., through the use of labels such as weak, medium, strong, or through an interval scale?
8. Fully quantified
   Guiding question: Does the study provide a numerical assessment of the interactions?

2017). Interaction qualifiers typically used to describe interactions in this approach include the labels indivisible, reinforcing, enabling, consistent, restricting, counteracting and canceling (Nilsson et al., 2016). Other labels used to determine hierarchies among the SDGs include if progress on the independent SDG/target is a "prerequisite" or "optional" to progress on the dependent SDG/target (Singh et al., 2018), or if goals are independent, dependent or serving as linkages between other goals (Kumar et al., 2018). Generally, links that positively influence other interaction entities are referred to as synergistic and generate co-benefits, whereas connections that impede progress on other interaction entities are referred to as trade-offs and pose goal conflicts (Maes et al., 2019). Synergies and trade-offs are sometimes further classified, for example in a study describing institutional synergies as complementary, supplementary, or core synergies (Bastos Lima et al., 2017).

Lastly, information is sometimes provided about the strength of an interaction. These interaction qualifiers could be interval or ordinal scales, e.g., ranging from −3 to 3 or − 4 to 4 (Fader et al., 2018; McCollum et al., 2018; Allen et al., 2018b), or indicating relative strengths through labels such as weak, medium, strong (De Jong et al., 2018; Neumann et al., 2018). Quantitative connection qualifiers go further and provide a numerical value to an interaction. These have been used to measure trade-offs between social and environmental SDGs (Scherer et al., 2018), to trace interactions across sectors in integrated assessment models (Moyer and Bohl, 2019), and to estimate the additional energy demand needed to meet different SDG targets (Santika et al., 2019).

3.3. Data sources

The sources of data used to underpin SDG interactions are diverse. From the literature included in this review seven main sources emerged, as shown in Fig. 6. Box 4 links the data sources to questions for the reading guide.

Most common is the use of the **scientific literature (D1)** as data source, or additionally grey literature, such as reports, policy documents, and news articles. Another source of data is **official databases (D2)**, compiled by the UN, WTO, FAO, or national, regional, or local offices. Also, relying on **expert and stakeholder knowledge (D3)** is common in SDG interaction studies. Specific data collection methods in this context include focus groups, workshops, interviews, and questionnaires. **Direct observations (D4)** as means of data collection have been used in contexts where the authors were directly involved in policy processes related to the SDGs (Bastos Lima et al., 2017), or in more participatory exercises (e.g., Hodes et al., 2018). The data collected from experts and stakeholders have been used to ensure relevance of proposed interactions in a specific context (Allen et al., 2017), as well as for making semi-quantitative and quantitative assessments of these relationships (Weitz et al., 2017). One study has treated a **model as data source (D5),** using the elicited data for analysis beyond the initial purpose of the model (Gyula et al., 2018). Also **spatial maps (D6)** have been used as a source of data (Pfaff et al., 2018). The last category included in the coding scheme is when the source of data is **not specified (D7).**

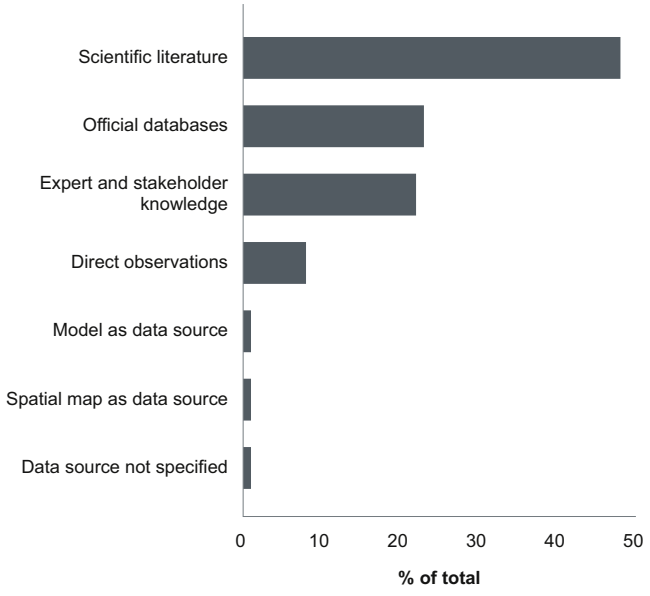

Fig. 6. Data sources typically used in SDG interaction studies (sub-codes as they occur in a percentage of the total sample).

Box 4
Reading guide: Data sources.

Seven types of data sources were found in the reviewed literature, as outlined below:

1. Scientific literature
   Guiding question: Does the study make use of the scientific or grey literature to underpin the existence of an interaction?
2. Official databases
   Guiding question: Does the study use data from official databases provided by, for example, UN statistics, WTO, FAO, or national statistical offices?
3. Expert and stakeholder knowledge
   Guiding question: Does the study elicit data from experts or stakeholders, including when the authors themselves provide data in their role as experts?
4. Direct observations
   Guiding question: Does the study include primary data collection through observation, e.g., through fieldwork or the authors of the paper directly engaging in the policy context they are aiming to understand?
5. Model as data source
   Guiding question: Are data extracted from a numerical or conceptual model to be used for a new analytical purpose?
6. Spatial map as data source
   Guiding question: Does the study extract data from maps?
7. Data source not specified
   Guiding question: Are the data sources explicitly stated?

3.4. How are SDG interactions identified and analyzed? Analytical approaches

A wide range of methods for data analysis are employed across the SDG interactions field, and we let nine overarching groupings illustrate them. An overview is provided in Fig. 7, while Box 5 outlines the associated questions for the reading guide.

Different types of **network analysis (M1)** have played a central role in SDG interaction studies. For example, network analysis has been used to visualize how SDG targets relate to the rest of the 2030 Agenda, highlighting clusters of strongly interacting targets (Weitz et al., 2017), and to perform causality analysis of SDG indicators (Dörgő et al., 2018). Moreover, keyword network analysis has been used to support the identification of overarching areas in need of integrated implementation to support the ultimate goal of sustainable development (Lim et al., 2018), social network analysis has been employed to understand the structure of water-energy-food nexus governance (Kurian et al., 2018), and to compare SDG network compositions for different country income levels (Lusseau and Mancini, 2019).

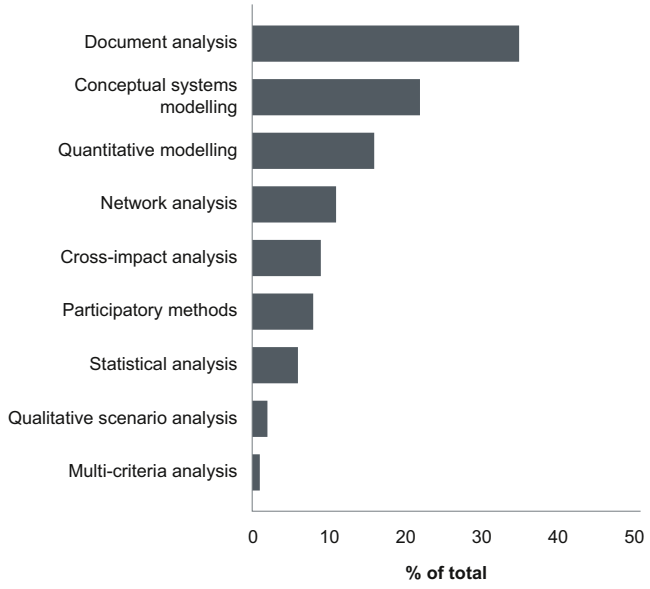

Fig. 7. Methods of analysis commonly employed in SDG interaction studies (sub-codes as they occur in a percentage of the total sample).

Box 5
Reading guide: Methods of analysis.

Nine groups of analytical approaches have been identified as frequently used in SDG interaction studies, as summarized and translated into guiding questions below:

1. Network analysis
   Guiding question: Does the study use analytical tools belonging to the network analysis family?
2. Cross-impact analysis
   Guiding question: Does the study perform scoring of interactions to be used as a basis for cross-impact analysis?
3. Participatory methods
   Guiding question: Does the study engage experts or stakeholders to support the analysis (e.g., to ensure relevance to regional context, to interpret targets, or to confirm the existence of an interaction)?
4. Quantitative modeling
   Guiding question: Is the analysis built on a quantified model of some sort?
5. Statistical analysis
   Guiding question: Does the study make use of statistics to identify or understand SDG interactions?
6. Conceptual systems modeling
   Guiding question: Does the study perform mapping of SDG interactions through conceptual models?
7. Document analysis
   Guiding question: Is document analysis used as a method in the study, either as the sole method or in combination with other methods?
8. Qualitative scenario analysis
   Guiding question: Does the study make use of qualitative scenario methods and tools?
9. Multi-criteria analysis
   Guiding question: Does the study employ multi-criteria analysis to address SDG interactions?

A second analytical group makes use of **cross-impact analysis (M2)** and semi-quantitative scales for clarifying the nature of SDG interactions, often departing from the question: If progress is made on SDG target X, how does this influence the attainment of SDG target Y? (Nilsson et al., 2016; Weitz et al., 2017). Some of these approaches use cross-impact analysis in combination with other methods to perform policy analysis (Allen et al., 2018b), other add to the analysis an exploration of infrastructure needs and input requirements, as well as benefits and risks for ecosystem services (Fader et al., 2018), or discussions on context-specific conditions and universality (McCollum et al., 2018).

Participatory methods (M3) have not only been used in the data collection phase, but also to analyze, revise, gain confidence in, and ensure the relevance of, specific SDG interactions. Hence, expert and stakeholder consultations could be used as an analytical tool. For example, tools for scenario development in a participatory setting have been used to gain an understanding of potential interactions between goals linked to reducing inequality, building secure societies, and enhancing overall sustainability (Glover et al., 2016). Expert consultations have been organized to interpret SDG targets, and to review suggested energy linkages with the SDGs (Santika et al., 2019). Regional experts and stakeholders have been consulted to ensure the relevance of an indicator-based framework in the Arab-region (Allen et al., 2017), and policy-makers have been engaged in the development of an integrated assessment model, aiming to understand interactions between poverty, livelihoods, and ecosystem service provision in coastal Bangladesh (Hutton et al., 2018). The level of stakeholder engagement varies in different studies, from only consulting the stakeholders involved, to transdisciplinary modes of research.

Various **quantitative modeling (M4)** methods have been employed or suggested useful to perform simulation-based analysis of SDG interactions across SDGs, targets, indicators and SDG-relevant sectors. These include System Dynamics modeling approaches (Kopainsky et al., 2018; Pedercini et al., 2018), integrated assessment models (Bijl et al., 2017; Hutton et al., 2018; Iyer et al., 2018; Moyer and Bohl, 2019), agent-based models (Guijun et al., 2017), computable general equilibrium models (Campagnolo et al., 2018), and input-output models (Scherer et al., 2018).

Often, these numerical modeling tools are used not only to identify SDG interactions, but also to perform scenario-analysis. For example, a simulation model has been used in combination with back-casting in a participatory setting to explore transition pathways in the agricultural sector (Kanter et al., 2016), an integrated assessment model (IMAGE) has been supporting the development of long-term scenarios for the energy and food systems (van Vuuren et al., 2015), and a partial equilibrium model (GLOBIOM) and the Shared Socioeconomic Pathways Scenarios (O'Neill et al., 2017) have been used to test policies and their impacts on long-term global food prices and environmental indicators (Obersteiner et al., 2016).

The potential for **statistical analysis (M5)** for analyzing SDG interactions has been increasingly stressed (Liu, 2017). SDG trade-offs and synergies have been understood as statistically significant negative and positive correlations between SDG indicator pairs (Pradhan et al., 2017), statistical analysis has been the basis for inferring interactions between SDG indicator pairs as part of a broader analytical framework (Dörgő et al., 2018), and to explore simulated results from a dynamic, partial equilibrium model (GLOBIOM), in the context of understanding change in environmental pressures and food prices (Obersteiner et al., 2016). Statistical methods have also been used to understand interactions between components of the 2030 Agenda as a basis for network analysis (Lusseau and Mancini, 2019).

A number of studies use **conceptual systems modeling (M6)** to understand SDG interactions. Causal Loop Diagrams have been used to explore feedback structures linking the SDGs together, subsequently finding system archetypes and leverage points to guide system interventions (Zhang et al., 2016). Cause and effect modeling has been

suggested useful to better understand SDG interactions and potential trade-offs between them (Neumann et al., 2018), and a conceptual diagram embedding SDG 2 in food system activities has been used to exemplify interactions, also with other SDGs (Kopainsky et al., 2018). A slightly different use is to develop conceptual maps for communication purposes, e.g., to highlight key interactions or feedbacks. In these studies, the conceptual diagrams might not serve as analytical tools in their own means, but are used as a complement. For example, Bijl et al. (2017) provide a conceptual overview of the linkages between the sectors of a numerical food demand model used in their analysis.

Hypothesized SDG interactions are commonly identified and analyzed through literature reviews and **document analysis (M7)**. Some studies use literature reviews as a sole method, such as Font Vivanco et al. (2018) in their analysis of policy-induced rebound effects, or as by Manandhar et al. (2018) to conceptualize the interlinkages between gender (SDG 5), health (SDG 3), and 13 additional SDGs. Other studies combine document analysis with other methods, such as direct observation (Bastos Lima et al., 2017), participatory scenario building (Glover et al., 2016), and conceptual frameworks (Allen et al., 2017).

A few studies perform **qualitative scenario analysis (M8)**. For example, existing foresight tools such as drivers of change, scenarios and wind-tunneling have been adapted to explore how to reduce inequality, accelerate sustainability, and build inclusive and secure societies (Glover et al., 2016). Also, food security scenarios have been developed, using a morphological grid, specifically aiming to address various sources of volatility, uncertainty, complexity and ambiguity (Sharif and Irani, 2017).

Only one study formally makes use of **multi-criteria analysis (M9)** as method. In their paper, Allen et al. (2018b) use what they refer to as a multi-criteria analysis decision framework to analyze and prioritize SDG targets. The prioritization is based on a target's perceived level of urgency, systems impact, and how it aligns with existing policy strategies.

3.5. Co-occurrence across sub-codes

Hitherto we only discussed themes and sub-codes individually or in partial combinations. As described in the Methods section, we utilized network analysis techniques and tools to explore patterns of co-occurrence among the sub-codes under policy challenges, conceptualizations in terms of interaction entities, data sources, and methods of analysis. The interaction qualifiers were not included in the analysis as they largely follow from the data sources and methods employed. The results show the emergence of three clusters, as visualized in Fig. 8. The nodes represent the sub-codes and the links are built up from how the articles are coded.

The yellow cluster depicts quantitative modeling research focusing on the study of interactions between SDG indicators (which are quantitative). The policy focus here is on prioritization of actions and outcomes as well as policy innovation. Within this cluster, contextualization of SDG interactions is important, and spatial maps occur as a data source. This goes hand in hand with a focus on indicators that are most often place-based. In general, this cluster of SDG interaction research sends a message that (globally) generalized conclusions about interactions and progress should be questioned; the scientific community should rather build detailed and empirically based models.

The red cluster represents more qualitative approaches where literature is an important data source, as well as direct observations by researchers monitoring real processes. The policy focus in this cluster is on integration and coherence, which also encompasses an integrated perspective with regards to stakeholder involvement. The utilisation of qualitative scenarios can be interpreted as a means to bridge both different policy areas as well as different stakeholder groups. This is the cluster where the "external entities" conceptualization of SDG interactions emerges, i.e., studies that connect to the wider policy landscape outside the 2030 Agenda itself. Hence, this cluster addresses issues like mainstreaming and alignment of the 2030 Agenda to existing policy.

In contrast, the green cluster is focused on the 2030 Agenda internally and encompasses research on goal-goal or target-target interactions, using tools and techniques related to network analysis. It also includes participatory approaches, and interacting with experts and other stakeholders to elicit data. It is interesting to note that this cluster of SDG interaction research has the weakest coupling to the policy challenges theme.

4. Discussion

4.1. The current focus of SDG interaction research

The SDG interactions field is diverse and rapidly evolving, spanning multiple scientific disciplines and domains. The results from our review highlight certain features and patterns of this field. Under the theme policy challenges, large attention has been directed towards enhancing overall policy coherence. This is not surprising given the close association between policy coherence and understanding how policy objectives (SDGs) interact. It may further be a consequence of the early stages of SDG implementation during which the studies reviewed here have been undertaken. Naturally, an immediate challenge to governments at this stage has been how to integrate, mainstream or align the 2030 Agenda with existing policy as they develop national action plans. In terms of conceptualizations of interactions, a majority of the studies focused on understanding how components of the 2030 Agenda interact with external entities. This is well in line with the intention to implement the SDGs within existing policy landscapes and processes rather than creating new parallel ones. The data sources used are largely made up by the scientific literature and official databases, which may not be surprising. However, also expert and stakeholder knowledge have played a vital role in SDG interaction studies. This may reflect an aim to understand highly contextual SDG interactions, a lack of access to data in numerical or written form, and a need to deal with uncertainty in respect to the future development of SDG interactions.

4.2. Gaps and potential future research avenues

Contrasting the sub-codes elicited in our review with current debates and intentions of the 2030 Agenda, we here discuss a number of gaps. Relatively little attention has been given to policy innovation, which may be surprising given the ambition to facilitate transformative change. Identifying new and innovative policy approaches and measures would be an expected next step, seeking to mitigate the trade-offs and enhance the synergies identified in interaction analyses. Under the heading of policy innovation, it is also worth mentioning the absence of studies addressing possible implications of new and emerging technologies, and the role they could play in implementing the 2030 Agenda.

Additionally, monitoring and evaluation have received relatively little attention, which may be problematic as this is key to measuring progress over time, to understanding policy impacts, and for ensuring accountability. The lack of a comprehensive SDG indicator framework and associated databases may partly explain this gap. Also the early stage of implementation may be part of the explanation, where country reporting to the UN High-level Political Forum on Sustainable Development (HLPF) focused on more qualitative assessments at national level, centered around subsets of goals. Also, UN reports present progress at an aggregated level (per goal at a global or regional scale). Linked to this gap is the question if also monitoring and evaluation in the realm of the 2030 Agenda should respond to a requirement of being integrative, and what that would imply in practice. Based on our understanding of the literature, none of the studies addressed this issue.

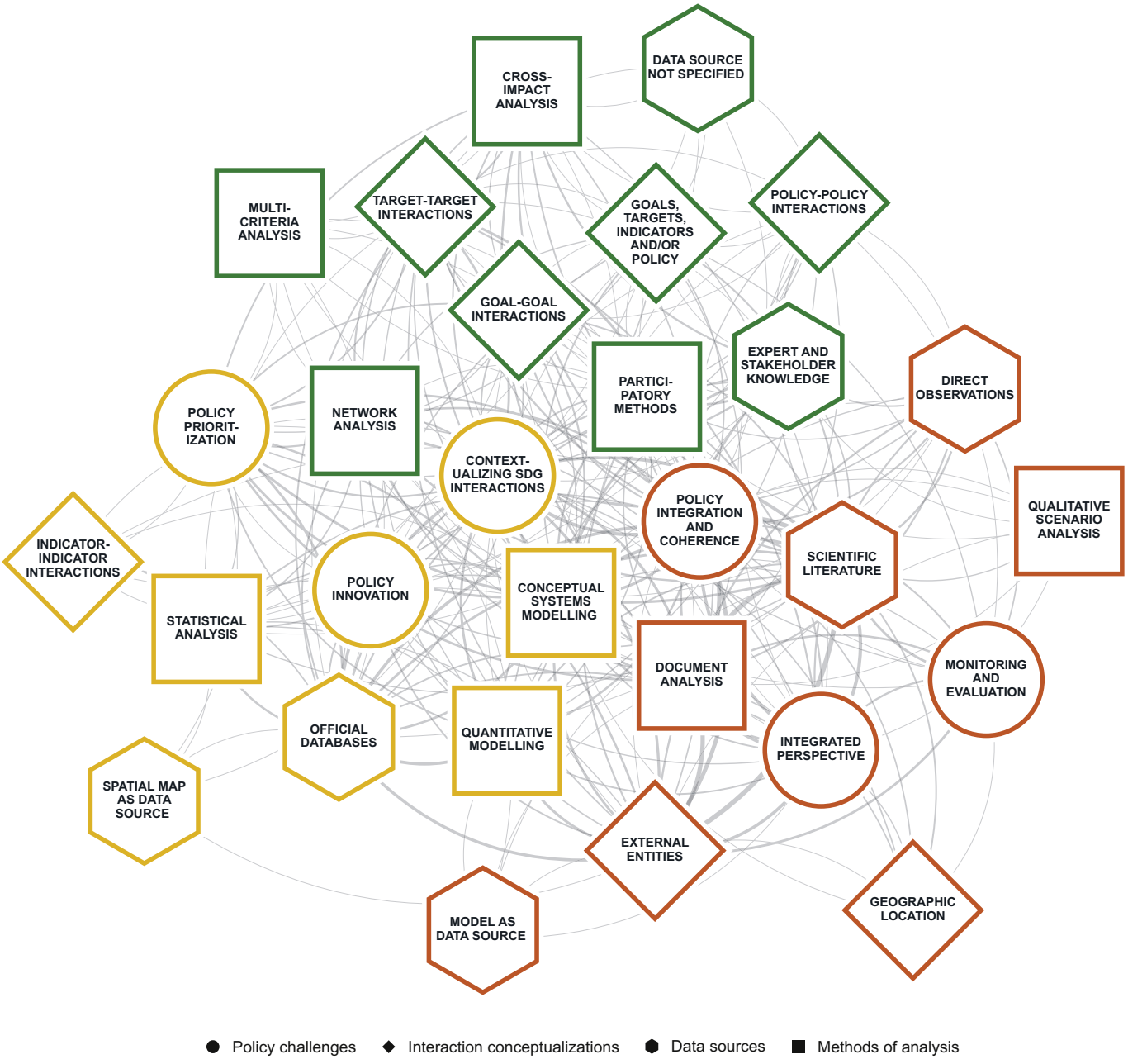

Fig. 8. Network of co-occurring sub-codes, with three main clusters emerging.

Further, very few studies assessed indicator-indicator interactions, which is not surprising given the lack of a complete indicator framework and data coverage. On the other hand, we see large attention directed towards quantitative analysis, considering the sources of data. Thus, perhaps a careful mapping of what existing databases cover and what gaps remain (including addressing integrated indicators and monitoring of systemic impact) should be the focus of the SDG monitoring community.

Approaching this review, we envisioned to find studies that considered actors linked to the implementation of the SDGs and how they interact. These studies would, for example, seek to understand patterns and determinants of shared and conflicting interests among implementing actors, and inform alternative ways of organizing implementation based on how the goals and targets interact. However, no such studies were found. Additionally, while policy integration and coherence is a topic that has received relatively large attention, coherence between the 2030 Agenda and other global agendas like the Paris Agreement is very sparsely addressed by our sample of SDG interaction studies. Yet another aspect that is poorly covered is the geographic location of SDG interactions. Without a better understanding of how progress on the SDGs in one place affects goal attainment in other places it remains challenging to measure global progress. Being a key principle of the 2030 Agenda, the universality dimension would need to be better represented in future SDG interaction studies, to ensure that no one is left behind in a highly globalized world.

Studies that take a truly systemic approach to the study of SDG interactions (i.e., cover the whole agenda and assess systemic properties and not just a subset of goals or targets) are relatively few. It is common to select a subset based on, for example, scientific interest or policy responsibility, potentially adding a few additional 'nearest neighbours'. These approaches run the risk of missing out on secondary and

higher-order effects in the network of SDG interactions, effects that could potentially promote transformative (i.e., systemic) change. The ethos of the 2030 Agenda as a unified, indivisible whole seeks to capture such transformative change. Moving beyond pairwise and partial analysis, unless the objective is to inform only a specific piece of the SDG puzzle, will be key for SDG interaction studies if seeking to guide implementation.

In terms of methods employed, they show that the level of participation is not necessarily high. Experts and stakeholders are mainly used as informants, but are not engaged in the research process in more transdisciplinary ways of conducting research. Other insights from the methods theme are that document analysis and conceptual systems modeling are the most frequently occurring modes of analysis, followed by quantitative modeling. To complement these approaches, there may be room to build further on qualitative scenario methods and link these to quantitative modeling approaches, to mention one example.

4.3. A note on recent publications and grey literature

Since the literature sampling for the present review took place, with a cut-off date in early 2019, a number of studies have been published that may contribute to addressing some of the gaps identified. For example, there are studies exploring how remote sensing data and modeling of ecosystems services can be used to assess SDG trade-offs and synergies (Mulligan et al., 2020), or studies seeking to improve the coverage of integrated assessment models in relation to the SDGs (van Soest et al., 2019). Other papers add to the discussion on how to monitor progress in an integrated manner (Biggeri et al., 2019), or set out to identify best practices in how to turn trade-offs into synergies in support of overall SDG progress (Kroll et al., 2019).

Also the grey literature may help cover some of the gaps identified. Methodological contributions have been made, for example by exploring how Natural Capital Accounting can support the implementation of the SDGs, by enhancing the understanding of interactions between the economy and the environment (Bann, 2016), or how a taxonomy of interactions can support the implementation process (Coopman et al., 2016). Additionally, there are studies assessing coherence between the 2030 Agenda and existing national goals or targets in an EU context (Niestroy, 2016), studies providing guidance on prioritization and sequencing of SDGs (Leitner, 2019), or performing analysis of how to meet the SDGs without overshooting planetary boundaries (Randers et al., 2018). Additionally, a number of online tools and platforms exist, aiming to facilitate the application of SDG interaction studies. Some examples include the Institute for Global Environmental Strategies "SDG Interlinkages Analysis & Visualization Tool" (IGES, 2019), the EU Joint Research Center's SDG dashboard showcasing interlinkages among the SDGs based on reviewed literature (Borchardt et al., 2019), the PWC "SDG selector" developed to help companies identify SDGs relevant to their business, given industry context, geographic area, and thematic considerations (PWC, 2019), the UN Environment Management Group's "Nexus Dialogues Visualization Tool" (UN EMG, 2019), and the Climate Watch tool that identifies interlinkages between the Nationally Determined Contributions (NDCs) of the Paris Agreement and SDG targets (ClimateWatch, 2019). Another opportunity to explore interactions between the SDGs and climate action is offered by the NDC-SDG connections tool (GDI and SEI, 2020). An additional model-based platform used to perform policy scenario analysis is the World Economic Forecasting Model at the UN, mainly focused on building an understanding of changes in the global economy (Altshuler et al., 2016). Further, the UN provides platforms collecting SDG interaction assessment tools, as submitted by the developers of these tools. The user may navigate these different tools based on the SDG of interest, the purpose of the assessment (e.g., assessing interactions among the SDGs or performing community-based planning) or based on the type of tool preferred (e.g., knowledge management platforms, scenario-tools, econometric tools) (UN, 2019). Other tools are used within the UN for policy planning and capacity building, but provided open source to an as large extent as possible (UNDP and UNDESA, 2019).

4.4. A reading guide to SDG interaction studies

The results outline various ways in which SDG interactions can be identified and analyzed, as summarized in the reading guide (Box 1-5). For the scientific community, we suggest that answering the guiding questions in the reading guide may be helpful both in a research design stage and research reporting stage. In the research design stage, it may help make explicit the link to SDG implementation, by clearly stating what policy challenge the study is aiming to address. In terms of reporting, we believe that future SDG interaction studies could easily be coded and mapped using the structure presented in the reading guide, thereby enhancing comparability with existing literature. Consistency in reporting may also support building databases and case study repositories, making the emerging literature more accessible. For decision- and policy makers, we suggest that answering the guiding questions in Box 1-5 when approaching the literature on SDG interactions may help to determine if the scope of an article is relevant and applicable to the policy-issue at hand. Also, the network map in Fig. 8 can be used to screen for an appropriate set of methods to help respond to a certain policy challenge.

5. Conclusions

Based on a sample of 70 peer-reviewed articles, the present paper gives an account of how the scientific community has approached the integrated nature of the 2030 Agenda. Four central themes in the sampled literature have been identified and mapped: the policy challenges typically addressed; how interactions across the SDGs have been conceptualized; the types of data sources used; and the methods of analysis employed. A number of research gaps, and potential research avenues, emerged from the analysis. Policy innovation and issues of integrated monitoring and evaluation are largely overlooked in the reviewed articles. There is also a need to be more explicit about what policy challenges the research responds to. In terms of how interactions have been conceptualized, few studies were found that consider geographic scales and spill-over effects or interactions across SDG indicators. Further, only a limited number of studies employ participatory methods or take a truly systemic approach to the 2030 Agenda. Finally, none of the studies in the reviewed sample consider interactions between the actors responsible for implementing the SDGs. Without addressing these gaps, there is a risk of inefficient implementation or, worse, a failure to realize the high-reaching ambitions of the 2030 Agenda.

To make the literature on SDG interactions more applicable and comparable, the paper also provided a reading guide. The reading guide does not attempt to bring an exhaustive list of themes and sub-codes, but it proposes a way to begin to conceptually organize the emerging literature on SDG interactions. We recognize the need to further develop and extend the reading guide, for example by adding new themes or sub-codes, and the structure proposed here should be flexible enough to incorporate such extensions. We firmly believe that better structure to the diverse field of SDG interaction studies could make the literature more broadly accessible, and thereby better able to contribute to successful SDG implementation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Overview of scientific articles included in the final sample

Alcamo, J., 2019. Water quality and its interlinkages with the Sustainable Development Goals. Curr. Opin. Environ. Sustain. 36, 126–140. doi:https://doi.org/10.1016/j.cosust.2018.11.005

Allen, C., Metternicht, G., Wiedmann, T., 2018. Prioritising SDG targets: assessing baselines, gaps and interlinkages. Sustain. Sci. 14, 421-438. doi:https://doi.org/10.1007/s11625-018-0596-8

Allen, C., Nejdawi, R., El-Baba, J., Hamati, K., Metternicht, G., Wiedmann, T., 2017. Indicator-based assessments of progress towards the sustainable development goals (SDGs): a case study from the Arab region. Sustain. Sci. 12, 975–989. doi:https://doi.org/10.1007/s11625-017-0437-1

Barbier, E.B., Burgess, J.C., 2017. The Sustainable Development Goals and the systems approach to sustainability. Econ. Open-Access Open-Assess. *E*-J. doi:https://doi.org/10.5018/economics-ejournal.ja.2017-28

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Table A1
Clusters of journals (grouped according to overarching focus/scope) and the number of articles belonging to each cluster.

No.	Cluster name	Total number of articles	Included journals (Number of Articles)
1	Broad multi/interdisciplinary scope	36	Current Opinion in Environmental Sustainability (3); Sustainability Science (7); Global Environmental Change (1); Sustainable Development (2); Environmental Science & Policy (3); Environmental Reviews (1); Sustainability (5); Earths Future (2); Systems Research & Behavioural Science (1); Environment, Development & Sustainability (1); Ecology & Society (2); Nature Sustainability (3); Environmental Research Letters (1); Nature (1); Futures (1); Science Advances (1); Frontiers in Environmental Science (1)
2	Politics, Law, Economics, International Development	11	Economics (5); International Environmental Agreements: Politics, Law and Economics (1); Ecological Economics (1); IDS Bulletin (1); Environment and Planning C: Politics and Space (1); Development Southern Africa (1); Transforming Government: People, Process and Policy (1)
3	Natural Resources	8	Nature Ecology and Evolution (1); Forests (1); Water (1); Land (1); Marine Policy (1); Ecosystem Services (1); The Environmental Sustainable Development Goals in Bangladesh - book (1); Managing Water, Soil and Waste Resources to Achieve Sustainable Development Goals - book (1)
4	Social Indicators	1	Social Indicators Research (1)
5	Engineering & Technology	4	Chemical Engineering Transactions (1); Technological Forecasting and Social Change (1); Österreichische Wasser- und Abfallwirtschaft (1); Engineering (1)
6	Climate & Energy	5	Nature Climate Change (2); Global Change Biology Bioenergy (1); Energy for Sustainable Development (1); Energy Research & Social Science (1)
7	Health	3	Journal of the International AIDS Society (JIAS) (1); Bulletin of the World Health Organization (1); Journal of Midwifery & Women's Health (JMWH) (1)
8	Agriculture & Food	2	Agricultural systems (1); Global Food Security (1)
	Total:	70	

Appendix B. Overview of articles, themes and sub-codes

Table B1 provides an overview of the articles included in the review. The codes assigned to each article is indicated by an (X), arranged by theme and the respective sub-codes.

Theme 1: Policy challenges. Sub-codes: Policy integration and coherence (P1), Policy innovation (P2), Contextualizing SDG interactions (P3), Policy prioritization (P4), Integrated perspective (P5), Monitoring and evaluation (P6).

Theme 2: Interaction conceptualizations. Goal-goal interactions (C1), Target-target interactions (C2), Indicator-indicator interactions (C3), Policy-policy interactions (C4), Goals, targets, indicators and/or policy (C5), External entities (C6), Geographic location (C7), Actor interactions (C8).

Theme 3: Data sources. Scientific literature (D1), Official databases (D2), Expert and stakeholder knowledge (D3), Direct observations (D4), Model as data source (D5), Spatial map as data source (D6), Data source not specified (D7).

Theme 4: Methods of analysis. Network analysis (M1), Cross-impact analysis (M2), Participatory methods (M3), Quantitative modeling (M4), Statistical analysis (M5), Conceptual systems modeling (M6), Document analysis (M7), Qualitative scenario analysis (M8), Multi-criteria analysis (M9).

Table B1
Articles, themes, sub-codes.

Article	Theme 1: Policy challenges						Theme 2: Interaction conceptualizations								Theme 3: Data sources							Theme 4: Methods of analysis								
	P1	P2	P3	P4	P5	P6	C1	C2	C3	C4	C5	C6	C7	C8	D1	D2	D3	D4	D5	D6	D7	M1	M2	M3	M4	M5	M6	M7	M8	M9
1. (Kopainsky et al., 2018)						X					X	X			X												X			
2. (Glover et al., 2016)				X						X		X			X		X							X			X	X	X
3. (Bijl et al., 2017)			X									X				X									X		X			
4. (Singh et al., 2018)			X	X			X								X		X							X			X			
5. (Pradhan et al., 2017)		X		X					X							X										X				
6. (Moyer and Bohl, 2019)		X	X									X				X									X		X			
7. (McGowan et al., 2018)			X	X			X										X					X								
8. (Elder et al., 2016)	X			X								X			X											X	X			
9. (Flörke et al., 2019)				X			X								X											X	X			
10. (Josephsen, 2017)						X						X			X												X			
11. (Obersteiner et al., 2016)	X	X			X							X				X									X	X	X			
12. (Gyula et al., 2018)					X							X			X				X			X			X			X		
13. (Heimann, 2018)	X											X			X								X							
14. (Cucurachi and Suh, 2017)	X					X						X			X												X			
15. (Rosenthal et al., 2018)	X		X									X				X		X							X					
16. (De Jong et al., 2018)			X	X								X			X		X									X	X			
17. (McCollum et al., 2018)	X		X		X							X			X		X						X				X			
18. (Kumar et al., 2018)				X			X								X		X						X			X				
19. (Wood et al., 2018)	X											X			X		X					X					X			
20. (Kanter et al., 2018)	X		X		X							X			X												X			
21. (Mainali et al., 2018)	X		X								X				X	X	X					X				X	X			
22. (Dörgő et al., 2018)	X								X							X						X				X	X			
23. (Santika et al., 2019)	X				X							X			X	X	X							X			X	X		
24. (Manandhar et al., 2018)	X				X	X						X			X											X	X			
25. (Bowen et al., 2017)	X				X	X						X			X			X									X			
26. (Iyer et al., 2018)			X									X				X									X					
27. (Lusseau and Mancini, 2019)	X		X				X	X								X						X			X	X				
28. (Allen et al., 2017)					X						X				X	X	X							X		X				
29. (Hoff, 2018)	X		X		X								X		X												X			
30. (Liu, 2017)	X		X		X								X		X											X				
31. (Stafford-Smith et al., 2017)			X								X		X		X												X			
32. (Blanchard et al., 2017)	X		X									X			X	X											X			
33. (Nilsson et al., 2016)	X		X				X	X		X	X										X		X							
34. (Nilsson et al., 2018)	X		X		X			X							X			X									X			
35. (Maes et al., 2019)	X				X							X			X												X			
36. (Chakraborty et al., 2018)	X					X						X			X		X	X									X			
37. (Costanza et al., 2016)						X						X			X												X			
38. (Zhang et al., 2016)	X						X								X		X									X				
39. (Collantes et al., 2018)					X	X						X			X			X									X			
40. (Liu et al., 2018)	X											X	X		X												X			
41. (Neumann et al., 2018)	X		X		X			X									X									X				
42. (van Vuuren et al., 2015)	X			X								X			X	X									X					
43. (Collste et al., 2017)	X		X									X			X	X									X					

Table B1 (*continued*)

Article	Theme 1: Policy challenges						Theme 2: Interaction conceptualizations								Theme 3: Data sources							Theme 4: Methods of analysis								
	P1	P2	P3	P4	P5	P6	C1	C2	C3	C4	C5	C6	C7	C8	D1	D2	D3	D4	D5	D6	D7	M1	M2	M3	M4	M5	M6	M7	M8	M9
44. (Sharif and Irani, 2017)	X				X							X			X														X	
45. (Hutton et al., 2018)	X		X		X		X									X								X	X		X			
46. (Jaramillo et al., 2019)				X				X									X					X	X							
47. (Allen et al., 2018a,b)	X		X	X				X							X	X	X					X	X	X			X			X
48. (Kline et al., 2017)			X									X			X	X											X			
49. (Lim et al., 2018)	X			X							X				X							X				X	X			
50. (Font Vivanco et al., 2018)		X								X					X												X			
51. (Pfaff et al., 2018)			X	X								X				X				X					X					
52. (Haines et al., 2017)				X								X			X												X			
53. (Keesstra et al., 2018)		X			X							X			X												X			
54. (Campagnolo et al., 2018)	X		X						X						X	X									X					
55. (Matsumoto et al., 2018)	X			X						X						X									X					
56. (Karlsson-Vinkhuyzen et al., 2018)	X				X	X						X			X												X			
57. (Campagnolo et al., 2018)				X							X					X	X								X					
58. (Yamamoto and Premji, 2017)	X											X			X												X			
59. (Hodes et al., 2018)					X	X						X					X	X						X						
60. (Bastos Lima et al., 2017)	X											X			X			X									X			
61. (Barbier and Burgess, 2017)	X			X			X					X				X									X					
62. (Pedercini et al., 2018)	X	X										X				X	X							X	X					
63. (Fader et al., 2018)	X							X									X						X							
64. (Blanc, 2015)					X	X		X							X							X								
65. (Weitz et al., 2017)	X		X	X	X			X									X					X	X				X			
66. (Scherer et al., 2018)			X	X				X								X									X					
67. (Kanter et al., 2016)			X		X					X		X			X		X	X						X		X				
68. (Ololade, 2018)	X							X				X			X												X			
69. (Alcamo, 2019)	X		X					X							X											X	X			
70. (Yillia, 2016)	X				X							X			X												X			

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