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Just another buzzword? A systematic literature review of knowledge-related concepts in sustainability science

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A R T I C L E I N F O

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A B S T R A C T

Knowledge is a vital resource for both understanding and addressing pressing social–ecological challenges of our time. Sustainability scientists have thus increasingly turned their attention to the role and relevance of knowledge for societal change. However, as identified in this study, the research landscape is very broad and fragmented, with little convergence on definitions between scholarly communities. We comprehensively map knowledge-related concepts and their uses in sustainability science, while eliciting points of agreement and controversy across bodies of literature. Clarifying terminology is a first step towards better empirical science and theory building, and ultimately enhances our ability to leverage knowledge for action and decision–making. Our analysis also suggests five entry points to thinking about knowledge in sustainability science: (1) knowledge as system; (2) as entity, or (3) as process; (4) knowledge for and through learning; and (5) knowledge at interfaces. We discuss how, taken together, these perspectives can contribute to a better understanding of the multiple ways in which knowledge can serve sustainability.

1. Introduction

Addressing the social-ecological issues of our times requires collective action towards matching human needs with current and future global resource constraints. Failure to do so may result in transgressing planetary boundaries and irreversibly altering the conditions that have made life possible on earth (Rockström et al., 2009). Sustainability science aims to provide insights into existing nature-society interactions as well as about the capacities of society to affect change (Clark and Dickson, 2003; Clark, 2007). In other words, it seeks to equip us with both knowledge about *what* the world is like, as well as *the choices* we have for achieving long-term sustainability (Kates et al., 2001). And yet, 30 years after the Brundtland report (UN-WCED, 1987), our society is still dominated by unsustainable behaviours and structures. This raises questions about the kind of research and knowledge that might contribute to reversing global environmental trends.

Recent voices have suggested that there is a disconnect between what we know and what we do as a society because we are not studying *how* we can create change. Many scholars have called for making scientific knowledge usable (Clark et al., 2016), actionable (Palmer, 2012), action-guiding (Grunwald, 2007), or action-oriented (Caniglia et al., 2020; Fazey et al., 2018). Some argue for investigating social change (O`Brien, 2013) via real-world experiments (Caniglia et al., 2017), or for researching deep leverage points for societal transformations, such as paradigm shifts (Abson et al., 2017). Others suggest that involving stakeholders in transdisciplinary projects (Klein et al., 2001; Lang et al., 2012; Mauser et al., 2013; Scholz and Steiner, 2015b) or co-production processes is the way forward (Norström et al., 2020; Turnhout et al., 2020).

Differences aside, there is shared agreement that knowledge is an essential component of our decision-making and actions, either at the level of individual choice or at broader scales of collective action (including science as one form of meta-action). In particular, transdisciplinary approaches in sustainability research have highlighted that knowledge needs to be understood in relation to other factors, such as interests, values, beliefs, power structures and institutions, all of which play important roles in supporting or hampering change (Avelino, 2017; Westley et al., 2011; Balvanera et al., 2017; Ostrom, 2007, 2009; Scoones et al., 2020). Hence, knowledge remains an elusive concept, also because it requires a lot of qualifiers: what is knowledge about; who creates it, how, and for which purposes; when and by whom is it used? To understand the role knowledge plays in societal change, we need to

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develop a clear vocabulary around its many aspects.

To date, there is no comprehensive overview of knowledge-related concepts in sustainability science. Existing reviews and syntheses (see Appendix A for a detailed discussion) have often focused on one concept at a time, e.g. knowledge exchange (Fazey et al. 2013), or they have narrowed their scope to specific contexts, for instance, knowledge mobilisation within integrated coastal management (Bremer and Glavovic, 2013). Faced with a vast and fragmented body of literature (see also Gerlak et al., 2018), scholars interested in the role of knowledge for sustainability must either limit themselves to a single facet of knowledge, or confront the difficult task of navigating a multi-disciplinary and often contradictory maze of concepts. "Knowledge" risks, thus, to lose its meaning and become a buzzword. Our review aims to avoid this risk by bringing together and critically comparing definitions and usages of knowledge-related concepts in sustainability science. We set out to answer the question: "what is this thing called 'knowledge' in sustainability science"[1]? Since this is an ambitious task in a fast-changing field of inquiry, we break it down into the following research questions (RQ):

RQ1. How has the sustainability science community engaged with the notion of "knowledge" and which related concepts are mainly used?

RQ2. What are points of agreement and controversy surrounding these concepts?

RQ3. What is a systematic way of thinking about knowledge that might enable better science to advance our understanding of its role in decision-making for sustainability?

We are not concerned with providing an overarching definition of knowledge, nor with debating its nature. Our goals are more limited. We start by exploring relevant trends and creating a conceptual reference guide to be used by researchers, decision-makers, and all those interested in the multiple linkages between "knowledge" and "sustainability" (RQ1 and RQ2). Subsequently, we reflect on our findings to provide a nuanced understanding of the multiple ways in which knowledge can support individual and collective actions towards sustainability (RQ3). The rest of the manuscript is thus structured as follows: first, we explain our methodology; second, we provide an overview of the evolution of literature on knowledge and sustainability; third, we address conceptualisations of most frequently encountered concepts, and present five entry points to understanding knowledge; lastly, we discuss the implications of our results and suggest avenues for future research.

2. Methods

2.1. Dataset selection

We searched the Web of Science and Scopus databases for articles containing terms related to knowledge and sustainability or environmental change. Because the word "knowledge" is often used in its common sense, we transformed it into a keyword by linking it to various processes, including forms of learning. Similarly, we did not consider grey literature because we expected it to take a *definitional* rather than a *conceptual* approach to knowledge-related terms (Davis and Ruddle, 2010). We identified two sets of keywords (Table 1), and validated them with expert colleagues at our university. Prior to the search, an analysis of key studies had shown that most papers dealing with knowledge concepts also employ process words in conjunction with the word "knowledge". For instance, a paper about "embodied knowledge" would almost certainly include mentions of knowledge *production* or *creation*. Consequently, the search terms in Set A were deemed sufficient to cover most of our target literature. All papers retrieved contained in their title, abstract or keywords at least one term from each set. Set B offers a broad operationalisation of what we will refer to in this paper as "sustainability science", although publications span across many disciplines.

[1] This is in reference to a famous book on philosophy of science: "What is this thing called science", by Alan Chalmers.

Table 1
Knowledge and sustainability keywords.

Set A	Set B
"knowledge *produc*"	"sustainab* transformation"
"knowledge *creat*"	"sustainab* transition"
"knowledge *generat*"	"sustainable development"
"knowledge *mak*"	"environmental change"
"knowledge *manag*"	"human-environment*"
"knowledge *use*"	"social-ecological"
"knowledge *diffus*"	"environmental governance"
"knowledge *disseminat*"	"sustainab* governance"
"knowledge *integrat*"	
"knowledge system*"	
"social learning"	
"sustainability learning"	
"policy learning"	

Fig. 1 illustrates the steps of the systematic literature review, following the PRISMA protocol (Moher et al., 2009). The initial search, carried out on July 27, 2016, rendered 1914 records for Scopus and 680 for Web of Science. We limited the results to journal articles in English, with an *average citation per year* of at least 1. The latter is consistent with our interest in identifying mainstream concepts. Acknowledging the delays in citing newly published work, this rule did not apply to articles from 2015 and 2016 which were all included. After removing duplicates, we were left with 969 publications, a number we considered large enough to sufficiently map the most important discussions surrounding knowledge and sustainability.

We screened all abstracts to exclude false positives, publications with no abstract, those for which no concept of knowledge or learning was in focus, as well as articles in which the word "sustainability" was used with the meaning of "enduring", but with no connection to human–environment interactions. We also excluded 154 articles for which we had no institutional access.

In a following phase, we assessed the full texts of 547 articles for eligibility and assigned them to one of three categories: "in-depth", "in" and "out". Papers marked as "out" were excluded on grounds similar to those in the screening phase. Under the "in" category we assembled for future reference a database of papers that engaged with knowledge concepts and sustainability, but that were otherwise not offering enough information to address all our research questions. We retained for our "in-depth" analysis those papers that explicitly dedicated at least a

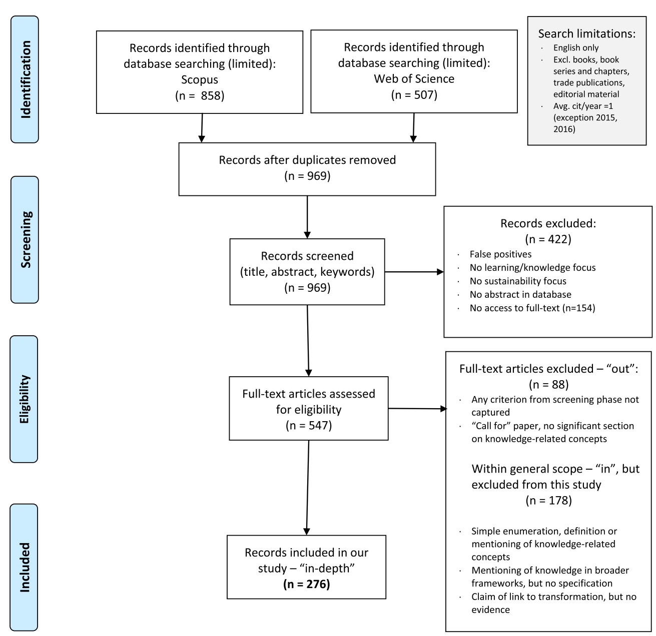

Fig. 1. PRISMA 2009 flow diagram (following Moher et al., 2009).

section to reviewing knowledge-related concepts or theories, offering new conceptualisations, or providing empirical evidence on how knowledge and learning contribute to sustainability (Appendix B). From the "in-depth" set, five more papers were excluded as false positives during coding. All data selection steps were carried out primarily by the lead author. For both screening and eligibility, we checked for biases in applying our exclusion criteria by conducting reliability tests and comparing results among four researchers and across time.

2.2. Data analysis

We coded 276 in-depth papers for *article type*, and primary and secondary *object of study*, i.e. main or secondary topic related to knowledge or learning (Table 2). Our codes were combined with downloaded bibliographical data to provide an overall context to how knowledge is addressed in sustainability science over time and across journals (RQ1).

In order to identify the most common concepts (RQ1), as well as to elicit their meanings (RQ2), we conducted a summative content analysis. This method is recommended when trying to understand concepts-in-use, and it starts with a set of keywords that are counted and compared, and subsequently interpreted in context (Hsieh and Shannonm, 2005). It deals with both manifest (explicit information in text, exact phrasing etc.) and latent content (deeper meaning, understanding etc.).

Fig. 2 presents the steps taken by the lead author to select and extract the meanings of the *concepts* that we discuss extensively in this article. Findings at each step (see Appendix C1) were thoroughly validated through periodical discussions with the co-authors. First, we excluded duplicates, consolidated coding and reduced the total set of *objects of study* to 148 *semantic constructs*, grouped under nine thematic categories. The categories emerged inductively from the data, and via an iterative process, and served the purpose of logically structuring the identified themes. Many of the 148 semantic constructs were too general to be searchable in other papers beyond our initial coding or there was no paper mentioning them more than four times (including references). Consequently, we further reduced the list to 75 unique, searchable knowledge-related *concepts* to be used as keywords for .pdf queries in the qualitative analysis software NVivo. For each keyword we recorded the total number of sources in which it appears ("number of papers *mentioning* the concept"), as well as how many of these sources contain the keyword at least five times ("number of papers *engaging* with the concept"). These numbers, together with the top code counts per category ("number of papers where concept is *in focus*"), informed our selection of the concepts addressed in detail in Section 4. Due to space limitations we restricted our analysis to 12 concepts, leaving out "transdisciplinary research" and "education for sustainable development", top concepts in what we considered to be rather tangential categories (see Appendix C1). Both these concepts are central to sustainability science, yet we appreciated that they focused on the "how" rather than on the "what" of knowledge, and thus did not directly

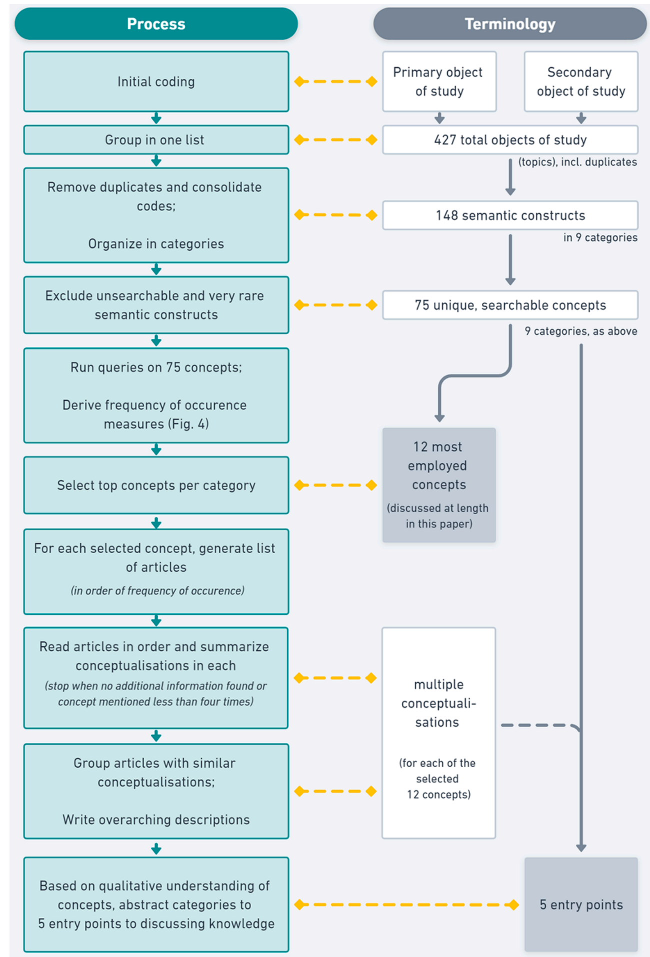

Fig. 2. Process for summative content analysis and terminology employed.[2]

Table 2
Coding of papers.

Code		Explanation
Article type	Conceptual	Publications presenting frameworks, concepts, classifications, but may also entail commentaries, argumentations, or calls for further research (agenda setting). Modelling work is also classified as conceptual work, unless strong reliance on empirical data.
	Empirical	Focus on the collection of primary data, with little conceptual work of their own, though sometimes providing overviews of the existing theories or concepts employed.
	Conceptual/ Empirical	Publications that present original conceptual insights or frameworks AND use empirical data to either illustrate or derive these.
	Review	Broad overviews of previous work, syntheses, *meta*-analyses.
Primary object of study		Main **knowledge**-related topic that the article gives considerable theoretical and/or conceptual attention to (*see Appendix B3 – criteria for "in-depth" selection)*.
Secondary object of study		Secondary **knowledge**-related topic that the article is addressing at length.
Year of publication		*Database field*
Journal		*Database field*

[2] Fig. 2 was drawn with free online tool available at: whimsical.com.

answer our overarching research question. For each chosen concept we read the relevant articles in the order of number of occurrences of the word (from highest to lowest, but no lower than four mentions) and captured the conceptualisations discussed in Section 4. To verify that we did not omit crucial perspectives, we selectively checked the "in" database for additional papers mentioning the concepts frequently. In general, this step did not add any significant information, which indicated that we had correctly identified the important papers in the eligibility round. Last, we abstracted the initial nine categories to five entry points for discussing knowledge, to represent the broad facets that this notion takes in the literature. Because the entry points are indirectly derived from our coding (Fig. 2), they ought to be understood within the inherent limitations of qualitative analysis.

3. Mapping the field: How has the sustainability science community engaged with knowledge?

Below, we present key findings addressing RQ1. The results of our analysis provide a snapshot of a vast, diverse and rapidly changing field. The map revealed here brings together various strands and flavours of sustainability science, ranging from inquiries around transformation and the role of scientists, to those rooted in the dynamic modelling of complex systems; and from transdisciplinary approaches to more analytical-descriptive ones. All these and many more are part of sustainability science and they engage with knowledge in different ways (Nagatsu et al., 2020). The underlying diversity of forms that the sustainability discourse has acquired globally over the years, as well as the academic institutions and funding agencies that have supported the emergence and development of sustainability science, have inevitably shaped the landscape of knowledge-related concepts and their

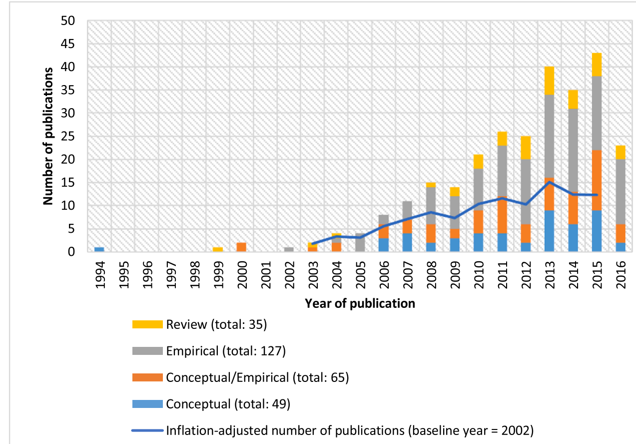

Fig. 3. Number of publications from 1994 to 2016, split by type.

Table 3
Journals with minimum three publications in our dataset, and number of publications by year.

	1994	1999	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total number of publications
Ecology and Society	0	1	0	0	0	0	0	1	3	2	1	1	8	7	6	8	4	6	48
Environmental Science and Policy	0	0	0	0	0	0	0	0	2	0	1	1	0	1	2	1	5	0	13
Global Environmental Change	0	0	0	0	0	0	0	0	1	1	0	2	1	0	0	2	1	0	8
Journal of Cleaner Production	0	0	0	0	0	0	0	0	0	0	1	0	0	0	6	1	0	0	8
Sustainability Science	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	1	3	8
Ecological Economics	0	0	0	0	0	0	0	0	0	2	0	1	0	0	2	1	1	0	7
Current Opinion in Environmental Sustainability	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	3	1	6
Environmental Management	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0	1	1	6
International Journal of Sustainability in Higher Education	0	0	0	0	0	0	0	1	0	2	0	0	2	0	0	0	1	0	6
Ambio	0	0	0	0	0	0	0	0	0	0	0	0	1	0	4	0	0	0	5
Environmental Education Research	0	0	0	0	0	0	0	0	0	1	0	4	0	0	0	0	0	0	5
Ocean and Coastal Management	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	3	0	5
Environment and Planning C: Government and Policy	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3	0	0	4
Futures	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	2	0	4
Journal of Environmental Management	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1	0	0	4
Journal of Sustainable Tourism	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	1	4
Proceedings of the National Academy of Sciences of the United States of America	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	2	4
Environment and Planning A	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	3
Environmental Conservation	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	3
Forest Policy and Economics	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	3
Society and Natural Resources	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	3
Sustainability	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	3

Table 4
Knowledge-related concepts in focus in top 23 journals. Values (v) represent the number of publications in each journal for which concept is a primary or secondary object of study. Only concepts and journals for which $v > 1$ are shown (full table in Appendix C2). The NA row sums up publications on periphery topics (not among the 75 *concepts*).

	Ambio	COSUST: Current Opinion in Environmental Sustainability	Ecological Economics	Ecology and Society	Environment and Planning C: Government and Policy	Environmental Education Research	Environmental Management	Environmental Science and Policy	Forest Policy and Economics	Futures	Global Environmental Change	International Journal of Sustainability in Higher Education	Journal of Cleaner Production	Ocean and Coastal Management	PNAS: Proceedings of the National Academy of Sciences of the United States of America	Sustainability Science	Water Resources Management
NA			3	17		3	2	3	3	2		3				2	2
boundary work								2									
education for sustainable development / ESD												2					
indigenous ecological knowledge				2													
indigenous knowledge				3													
knowledge coproduction				2				2									
knowledge integration				2										2		2	
knowledge production	4			3				2									
knowledge system		2		5				2							2		
knowledge to action				3											2		
knowledge utilization				2	2												
learning network													4				
local ecological knowledge				2													
mutual learning						2											
science-policy								2									
science-practice											2						
science-society				2				2									
social learning			3	17			2	4					2				
sustainability learning												2					
transdisciplinary / TD research										3							
traditional ecological knowledge				3													

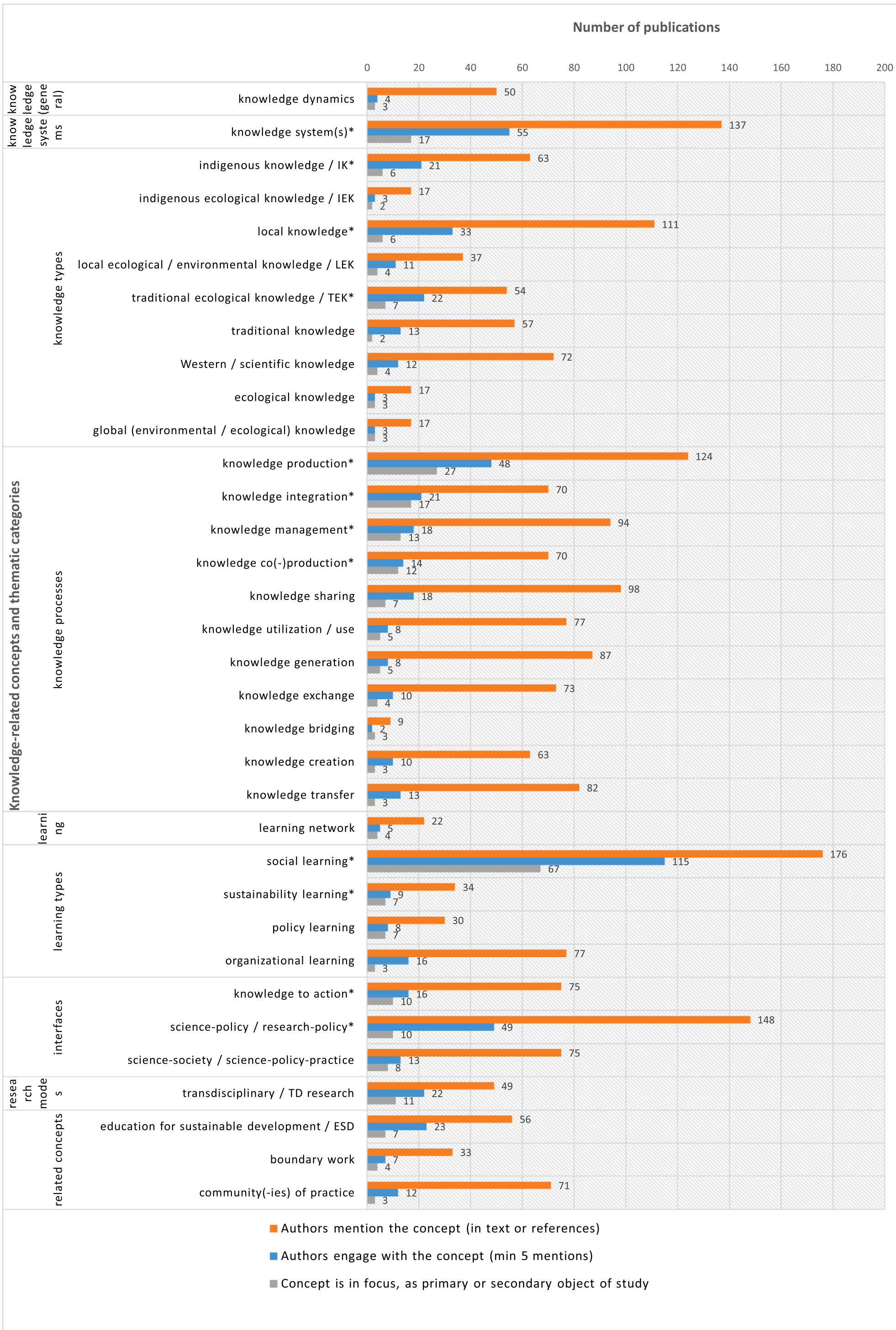

Fig. 4. *Focus* on vs. *engagement* with vs. *mentions* of knowledge-related concepts. 12 concepts marked with an asterisk (*) were selected for further analysis.

understandings (Bettencourt and Kaur, 2011; Mooney et al., 2013). Such complexities are partially captured here, and become even more visible in Sections 4 and 5.

Level of interest for knowledge-related themes is increasing, but field still in its infancy. The total number of publications engaging with knowledge-related concepts has increased over the period 1994 to 2016. The line in Fig. 3 indicates the number of publications adjusted for the growth in academic publishing relative to 2002 (following Abson et al., 2014). Almost half of the papers (46%, n = 127) are empirical-only, while a further 17.8% (n = 49) are conceptual or discussion papers, and 13% (n = 35) are reviews and synthesis articles (Fig. 3). About a quarter of the papers are conceptual contributions, which are then illustrated or tested empirically (23.6%, n = 65). The latter might indicate a lack of maturity of the field, in the sense that scholars keep developing their own new frameworks, for lack of established ones they can refer to.

A few journals drive the agenda for knowledge-related themes. The 276 articles examined were published in a total of 115 journals, yet only a few of them concentrate the knowledge–related literature in sustainability science: 23 journals have at least three articles in our dataset, and together they account for 59% (n = 163) of the publications (Table 3). The journal "Ecology and Society" alone published 17% (n = 48) of the in-depth articles.

Some journals tend to specialize on particular aspects of knowledge. We wanted to see which knowledge topics are published in which of the top 23 journals. Table 4 shows, for each journal, those concepts that are primary or secondary object of study in at least two articles. While "Ecology and Society" and "Environmental Science and Policy" publish on a broad range of knowledge-related aspects, other journals exhibit a preference for specific concepts, which might not be explainable by the small number of data points alone (e.g. "Ambio" or " Journal of Cleaner Production").

Knowledge-related concepts are often mentioned, but rarely in focus or rigorously addressed. Fig. 4 shows a subset of the 75 unique concepts we identified, specifically those that were *in focus,* i.e. coded as primary or secondary object of study, in at least three publications. We compare these numbers with the total number of *mentions* of the same concepts (simple count of sources in which the word appears), as well as with the number of publications that *engaged* with the concept (i.e. mentioned it at least five times). Note that the three measures in Fig. 4 need to be interpreted with caution when making comparisons across concepts; this is because some of the concepts were also keywords in the initial search, while others were not. We cannot say, for instance, that the "social learning" literature is 6 times bigger than the "transdisciplinary research" one, simply because there are more papers in our dataset mentioning it. Rather, the main message visualized in the figure is that a relatively small proportion of all publications discuss at length the knowledge-related terms they employ. This may indicate that knowledge concepts are often used rather casually, without thoroughly explicating their meaning.

Overall, we note that sustainability science literature abounds of knowledge-related terms, but few papers make them central to their inquiries. The extent to which there is agreement on their meanings and use is addressed next.

4. Organising the field: Delimiting knowledge in sustainability science

We now discuss the selected 12 most-employed knowledge-related concepts (marked with * in Fig. 4). For each, we summarize in Table 5 key definitional elements, as informed by *de facto* uses in the literature. Where divergent interpretations exist, we capture points of agreement and controversy (RQ2). With respect to RQ3, we use the categories in Fig. 4 and our understanding of the analysed concepts to derive five entry points to thinking about knowledge in sustainability science:

- Knowledge as system;
- Knowledge as entity (in a system);
- Knowledge as process (in a system);
- Knowledge for and through learning;
- Knowledge at interfaces.

We call these "entry points", because concepts illustrating any one of them often have implications that connect them to the others. For instance, knowledge co–production may start from a process view, but some accounts of it extend to the role of knowledge at interfaces between societal spheres. These five entry points do not exhaust the whole field. Several contributions have addressed issues related to the overarching concept of *knowledge* more generally[3], for instance, relying on the conventional definition of knowledge as "justified belief" (Wu et al., 2013) or "information that has been processed through learning" (Sheate and Partidário, 2010). Yet, taken together, the perspectives above can help articulate an overview of how knowledge is understood in sustainability science.

We acknowledge that other ways of delineating and naming the five entry points above would have been tenable based on the data. This is a limitation of the method. However, the names we settled on here closely match the language of the initial codes and categories and were left general enough to allow for subsuming under each of them a multiplicity of approaches and the diversity of vocabulary characterizing conversations about knowledge in sustainability science. It can be argued that most publications in our dataset take a systems perspective on knowledge, in the sense that they conceive of it as situated within and dependent upon many interconnections between elements and processes of social life. Our wording also reflects this underlying assumption and emphasizes the complementarity of the five elicited perspectives.

In the following sections we elaborate on these ideas and present conceptualisations of the most employed terms. For quick reference, each conceptualisation is listed under its own bullet point.

4.1. Knowledge as system

A first entry point to understanding knowledge takes a holistic perspective. Knowledge is not just a quantity or quality, nor does it pertain to a mere procedure or action. Instead, its nature is thought of as multidimensional, requiring a concomitant focus on the set of relevant elements, their inter-linkages, and any properties emerging from the interactions. Knowledge does not only exist in a system, it *is* the system itself.

The term ***knowledge system*** is central here, often encountered in combination with attributes such as: *environmental, traditional, agricultural, open* (see column "Knowledge systems" in Appendix C1). Clear definitions are often lacking, or when they do exist, they point to very different interpretations of the term. We identify three overarching conceptualisations:

- First, a knowledge system may refer to a **"way of knowing"** held by an individual, a group or a culture (Rathwell et al., 2015; Bohensky and Maru, 2011; Ahlborg and Nightingale, 2012; Gray et al., 2012), comprising of representations of the world (e.g. mental models), associated beliefs and practices (Gray et al., 2012), and often necessarily embedded into local geographical contexts (Rathwell et al., 2015). This conceptualisation is usually implied when contrasting different epistemologies, for instance: Western scientific vs. indigenous or local (Díaz et al., 2015; Bohensky and Maru, 2011; Ahlborg and Nightingale, 2012; Robinson and Wallington, 2012), traditional vs. modern agricultural knowledge systems (Reyes-García et al., 2014), hegemonic vs. bottom-up (Barkin, 2012). It is also used

[3] Related concepts were initially coded under the category "Knowledge (general)". See Appendix C1.

Table 5
Summary of conceptualisations of most-employed terms.

Entry point	Concept discussed	Conceptualisations or perspectives (streams of thought) regarding the concept	Attributes/characteristics of perspective	Examples of publications taking each perspective
Knowledge as system	Knowledge system	As a “way of knowing”/epistemology	• Internal representations of the external world (“mental models”) • Held by an individual, a group or a culture • Used in discussions calling for integration of plural perspectives	(Rathwell et al., 2015; Bohensky and Maru, 2011; Ahlborg and Nightingale, 2012; Gray et al., 2012; Díaz et al., 2015; Robinson and Wallington, 2012; Reyes-García et al., 2014; Barkin, 2012; Bremer and Glavovic, 2013a, 2013b; Zinngrebe, 2016; Muñoz-Erickson, 2014b)
		As formal or informal networks	• Emphasis on relational aspects • Used in discussions of knowledge interfaces	(Weichselgartner and Kasperson, 2010; Muñoz-Erickson, 2014b; van Kerkhoff and Szlezák, 2016; Cornell et al., 2013; Lubell et al., 2014; Cash et al., 2003; Tàbara and Chabay, 2013)
		Spanning across both views above	• Coherent cognitions and practices, as well as associated stable networks	(O’Toole and Coffey, 2013; Anderson, 2015)
Knowledge as entity	Traditional (ecological) knowledge (TK/TEK)		• Drawing on work by Berkes (1999) • Mixture of observations, practices, values and ethics, culture (see also Houde, 2007; Usher, 2000; Prober et al., 2011) • Often discussed in the context of comanagement • Usually seen as subset of IK/IEK	(Butler et al., 2012; Fernández-Giménez et al., 2006) (Armatas et al., 2016; Raymond et al., 2010; Bohensky and Maru, 2011)
	Indigenous (ecological) knowledge (IK/IEK)	*In practice, these concepts are often used interchangeably (because of lack of enough specification). Sometimes scholars also refer to traditional or indigenous knowledge systems. In that case, the entry point is rather “knowledge as system”, specifically in the sense of “way of knowing”.*	• Related to indigenous peoples • Imply a holistic worldview, but local and temporal dimensions are important, as well as transmission modes	(Holmes and Jampijinpa, 2013; Bohensky and Maru, 2011; Cullen-Unsworth et al., 2012; Watson, 2013; Gratani et al., 2011; Rathwell and Armitage, 2016; Nyong et al., 2007)
	Local (ecological/ environmental) knowledge (LK/LEK)		• Emphasizes connection to place and cultural embeddedness • Broad content • Sometimes contrasted to managerial/ scientific knowledge, viewed as complementary, yet less value-based than TK/ TEK	(Knapp et al., 2011; Ahlborg and Nightingale, 2012; Murdoch and Clark, 1994; Siebert et al., 2008; Adams et al., 2014)
Knowledge as process	Knowledge production	Mode 1/Mode 2 debate on doing research	• Concerned with the research process and the extent to which it can take an outside perspective on its object of study • Based on a dichotomy of “old” and “new” ways of doing knowledge • Drawing on Nowotny et al. (2001) and Gibbons (1994) • Sometimes emphasizing complementarity of the two modes.	(Brunet et al., 2014; Berker and Bharathi, 2012; Cooper, 2002; Schut et al., 2014) (Duru, 2013; Miller et al., 2011)
		Sociology of knowledge perspective on science	• Discusses scientific process in a broader cultural and historical context • Issues of power, colonialism and hegemonic systems are addressed	(Zingerli, 2010; Sletto and Nygren, 2015; Miller, 2005; Maiello et al., 2011)
		Joint knowledge production	• In policy and governance literature • Process at the interface between science and policy, conceptualised as taking place within the context of specific projects	(Hegger and Dieperink, 2014; Hegger et al., 2012a, 2012b; Offermans and Glasbergen, 2015; Rist et al., 2007)

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Table 5 (*continued*)

Entry point	Concept discussed	Conceptualisations or perspectives (streams of thought) regarding the concept	Attributes/characteristics of perspective	Examples of publications taking each perspective
		Transdisciplinary knowledge production	• Methodological discussions in science • Emphasis on dichotomy between academic/ non-academic actors • Stages of process are central	(Payne and Shepardon, 2015; Angelstam et al., 2013a; Polk and Knutsson, 2008)
	Knowledge co(-)production	Social critique model	• Discusses how knowledge and social order influence each other • Drawing on Jasanoff (2010) and Latour (2004)	(Watson, 2013)
		Instrumental model	• Situated within collaborative processes that aim to solve specific policy problems	
		• Institutional level	• In relation to co-management and adaptive governance • Central role for bridging and boundary organizations	(Armitage et al., 2011; Reyers et al., 2015)
		• Project level	• Joint work of multiple actor groups	(Davidson-Hunt et al., 2013)
	Knowledge integration	Renewing vs. bringing together model of integration	Renewing • Subordination relation between two or more knowledge systems (in a “way of knowing” perspective) • Process of updating knowledge within the same system over time	(Bohensky and Maru, 2011; Butler et al., 2012; Eidt et al., 2012)
			Bringing together • A process for dealing with fragmentation of knowledge to reduce uncertainty and risk • Equal stances for various perspectives	(Stepanova, 2015; Shiroyama et al., 2012; Scholz and Steiner, 2015a)
			Beyond renew and bringing together (towards decision-making)	(Gray et al., 2012; Sindakis et al., 2015; Sandhawalia and Dalcher, 2015)
		Process vs. outcome (product)	Process • Emphasizes steps to be taken for integration/ questions to be considered	(Raymond et al., 2010)
			Outcome/product • Integration assessed ex-post	(Soria-Lara et al., 2016; Robinson and Wallington, 2012; Cullen-Unsworth et al., 2012; Fernández-Giménez et al., 2006)
			Combined views	(Evans et al., 2011; Knutsson, 2006)
	Knowledge management (KM)	Standard knowledge management literature	Functionalist understanding, building on Nonaka (1994) • Strategic system for organizational learning • Sustainability as application of innovation or customer-oriented organizational processes	(Preuss and Córdoba-Pachon, 2009; Yang et al., 2015; Ayuso et al., 2011; Evangelista and Durst, 2015; Meese and McMahon, 2012; Wu and Haasis, 2013; Siltaoja, 2014; Sindakis et al., 2015; Sandhawalia and Dalcher, 2015)
		As part of resource management theory / sustainability science	• Attempts to bring standard KM literature into other fields • Looks at relations of knowledge management to other knowledge processes • Knowledge management as variable in overarching frameworks	(Blackmore, 2007; Offermans and Glasbergen, 2015; Schut et al., 2014; Rogers et al., 2000; Hayles, 2010)

(*continued on next page*)

Table 5 (*continued*)

Entry point	Concept discussed	Conceptualisations or perspectives (streams of thought) regarding the concept	Attributes/characteristics of perspective	Examples of publications taking each perspective
Knowledge for and through learning	Social learning[a]	Change within an individual	• Can be due to: • learning influenced by social norms (drawing on Bandura, 1977, qtd. in Reed et al., 2010) OR • as a result of participating in a process (Rodela, 2011: "individual-centric perspective")	(Medema et al., 2014; Blackstock et al., 2009; Garmendia and Stagl, 2010)
		Process of social change	• Often conflated with stakeholder participation (Reed et al., 2010) • Can happen either at the level of: • multi-stakeholder platforms (Rodela, 2011: network-centric view) OR • institutional settings (Rodela, 2011: system-centric view)	(Ensor and Harvey, 2015; Cundill et al., 2014; Lee and Krasny, 2015; Sol et al., 2013)
	Sustainability learning	Social learning with a normative element	• Drawing on work by Tàbara et al. (2007) • Social learning, but with a specific goal related to understanding social-ecological systems and how to manage them.	(Polk, 2011; Hansmann, 2010; Tàbara and Pahl-Wostl, 2007)
		Stemming from research and education sciences	• Related to transdisciplinarity • *Transformative sustainability learning* as a pedagogy	(Scholz et al., 2006) (Sipos et al., 2008)
Knowledge at interfaces	Interface: knowledge-to-action	Actors and networks as central	• Both informal and formal networks are central • Linking done through knowledge systems ("network' perspective)	(Muñoz-Erickson, 2014a, 2014b; van Kerkhoff and Szlezák, 2016)
		Brokerage and boundary work as central	• Linking requires mediating institutions and structures, or policies • Scientists should also play a central role	(Talwar et al., 2011; Wyborn, 2015; Cash et al., 2003; Shanley and López, 2009; Cornell et al., 2013; Shaw and Kristjanson, 2014; Clark et al., 2016; Charron, 2012; Berbés-Blázquez et al., 2014)
	Interface: science-policy/research-policy	"A gap to be closed" model	• Bridging and boundary organizations, as well as institutional processes (including KM) as key in linking science and policy	(Hickey et al., 2013; Crona and Parker, 2012; Sindakis et al., 2015; Sternlieb et al., 2013; Cash et al., 2003; Fogel, 2005; Heland et al., 2014; Pihlajamäki and Tynkkynen, 2011)
		Coproductionist model	• Interplays between science and governance are recognized • Linked to knowledge coproduction models discussed above • Science-policy interface sometimes seen as part of broader types of arrangements (networks, multiple boundaries between societal spheres etc.)	(van Kerkhoff and Lebel, 2015; Hegger et al., 2012a, 2012b; Hegger and Dieperink, 2014; Bremer and Glavovic, 2013a, 2013b; Schut et al., 2014; Vogel et al., 2007)

[a] "Social learning" was a dominating concept in our dataset (n = 67 articles with it as primary or secondary object of study), but elicitations of its various conceptualisations already exist, so in our discussion we draw on the latter, rather than on our primary data. We do, however, give examples of papers in our dataset that illustrate the respective conceptualisations.

in works calling for a plurality of perspectives and their integration (Bremer and Glavovic, 2013; Zinngrebe, 2016). When operationalised for empirical research, knowledge systems as ways of knowing comprise of: major epistemology, information and data systems, practices and technologies (Muñoz-Erickson, 2014b).

- Second, the term *knowledge system* may be used to refer to formal or informal **"networks"** within which knowledge is produced, exchanged and used (van Kerkhoff and Szezák, 2016; Cornell et al., 2013; Lubell et al., 2014). Emphasising *relational* aspects between actors or institutions (Weichselgartner and Kasperson, 2010; Muñoz-Erickson, 2014b), this conceptualisation is primarily employed in discussions about how to translate knowledge into action, or how science and research should be reorganized to foster sustainable development (Cornell et al., 2013; Cash et al., 2003; Tàbara and Chabay, 2013). Evans (2010) compares this more dynamic view, focusing on how knowledge evolves via network interactions, with the previous, more static one, with systems as groups of users with relatively stable cognitions and practices.
- Third, in some cases the two conceptualisations **are combined** and knowledge systems are considered, following Röling and Jiggins (1998) as ways of knowing, as well as actors and institutional networks (O'Toole and Coffey, 2013; Anderson, 2015).

4.2. Knowledge as entity

Articles in this category focus on knowledge as described through a set of attributes. Similarly to the concept of *knowledge resources* (Böschen, 2013; Polk, 2011), they point to knowledge as a stock or a "thing" that can be possessed by an individual or a group and that may serve as an input to a process or an outcome thereof. Most concepts initially clustered in the "Knowledge types" category fit here, each emphasising one or multiple dimensions: method of acquisition (*transdisciplinary knowledge*, *scientific knowledge*, *vernacular knowledge*), temporal or spatial scales (*local or global knowledge*, *traditional knowledge*, *foresight knowledge*), owner of knowledge (*expert knowledge, fishers' knowledge*), object of knowledge – what it is about (*system knowledge*, *normative knowledge*, *sustainability knowledge, CSR knowledge*), etc.

We address in detail the three most frequently encountered concepts: ***traditional knowledge*** or ***traditional ecological knowledge (TK/TEK), indigenous (ecological) knowledge (IK/IEK)***, and ***local (ecological/environmental) knowledge (LK/LEK)***. In most publications, clear delineations between these terms are absent and they are often used interchangeably (Baival and Fernández-Giménez, 2012; Johnson et al., 2015; Gratani et al., 2011; Hopping et al., 2016; Evans et al., 2011; Murdoch and Clark, 1994). However, there is some agreement that they all refer to: "a people's (1) shared system of knowledge or other expression about the environment and ecosystem relationships that is (2) developed through direct experience within a specific physical setting, and (3) is transmitted between or among generations" (Davis and Ruddle, 2010, p. 884). This hints to an understanding of knowledge as system (see above), especially when TK/IK/LK are discussed in contrast to Western or scientific knowledge. Yet, in practice these terms are often employed casually, the word "system" is missing, and the focus is on the attributes, rather than on the relation with broader cultural aspects, hence we include them here. Below we clarify differences between these concepts.

4.2.1. Traditional (ecological) knowledge (TK/TEK)

TK/TEK conceptualisations mostly draw on Berkes (1999) and are employed within the context of comanagement, calling for integration with Western scientific knowledge (WSK) in order to enhance social–ecological resilience (e.g. Butler et al., 2012; Fernández-Giménez et al., 2006). TEK is acquired through observation and direct experience (Berkes, 1999; Falkowski et al., 2015; Prober et al., 2011) and is often local (Butler et al., 2012; Alessa et al., 2008; Colding et al., 2003; Reyes-García et al., 2014). Some scholars conflate it with *LEK* (Hopping et al., 2016), though others consider the latter to be based in more recent human-environment interactions rather than in well-ingrained traditional practices (Raymond et al., 2010). Yet other authors understand TEK as a subset of *IK* that specifically deals with ecological processes and humans' role in them (Armatas et al., 2016; Raymond et al., 2010; Bohensky and Maru, 2011). Lastly, TEK is viewed as multi-faceted, comprising, for instance of: factual observations, management systems, past and current uses of the local environment, ethics and values, culture and identity, and a cosmology (Houde, 2007, see also Table 1 in Prober et al., 2011, for similar taxonomies).

4.2.2. Indigenous (ecological) knowledge (IK/IEK)

IK/IEK mainly refers to a holistic worldview of indigenous peoples (Cullen-Unsworth et al., 2012), comprising of elements beyond ecology (Bohensky and Maru, 2011). Accounts of *IK* often take a post-colonial stance in how they address power and validity (Watson, 2013; Gratani et al., 2011). They also emphasise modes of transmission across generations, especially forms of cultural expression such as oral traditions or art (Rathwell et al., 2015; Nyong et al., 2007). In one of the few attempts to elicit the content of IEK, Holmes and Jampijinpa (2013) propose a framework that uses Indigenous peoples' (Warlpiri perspective) categories, e.g. *law* for guiding principles; *skin* for responsibilities towards people and country; *language* for communication elements, including non-verbal; *ceremony* for education.

4.2.3. Local (ecological/environmental) knowledge (LK/LEK)

LK/LEK emphasises the connection to a specific place (Lebel, 2013) and includes anything from knowledge about physical and biological indicators, to understanding the behaviour of plants and animals, to awareness of change (Lebel, 2013; Fernández-Llamazares et al., 2015). LK/LEK is embedded in cultures, daily practices, and formal and informal institutions (Pretty, 2011; Knapp et al., 2011; Ahlborg and Nightingale, 2012), and, in contrast to general scientific principles, it offers contextualized understandings, thus being a useful complement to, e.g. quantitative, fieldwork-based ecological data (Knapp et al., 2011). However, LK may also sometimes be detrimental to the environment (Murdoch and Clark, 1994). Siebert et al. (2008) point out that in our global society it is important to distinguish between *local knowledge*, as being rooted in the long-standing practices of that particular place, and *knowledge of locals*, possessed by local actors, who might have moved from somewhere else. Finally, LEK is the preferred term when discussing long-term, lay observations in European settings, as it can be perceived to be less value-based than TEK (Adams et al., 2014).

4.3. Knowledge as process

This perspective focuses on actions, rather than properties, and the flows by which knowledge moves within a system. Some are production- and application-related processes (e.g. *knowledge production, co-production, generation, creation, making, utilisation, mobilisation, management*), while others are related to transfer and mediation (e.g. *knowledge sharing, exchange, transfer, dissemination, integration, brokerage*).

Special attention in the sustainability literature is given to processes of knowledge ***production, co-production, integration,*** **and** ***management,*** although meanings are also in this case often conflated or confounded.

4.3.1. Knowledge production

The notion of ***knowledge production*** is closely associated with scientific research (e.g. Angelstam et al., 2013b) and definitions, when present, are broad (Böschen, 2013, p. 81). **Four main streams of thinking** about knowledge production processes emerge from the literature:

- A first stream situates knowledge production within **debates about Mode-1 and Mode–2 science** (Gibbons, 1994; Nowotny et al., 2001) where the latter emphasises a problem-solving orientation, a transgressing of the boundaries of universities towards society, and the inclusion of a large range of actors. Publications in this group appear most frequently in fields such as engineering or innovation studies, and the meaning transgresses the boundaries between generation and use of knowledge, thus resembling co-production, as conceptualised below (e.g. Brunet et al., 2014; Berker and Bharathi, 2012; Cooper, 2002; Schut et al., 2014). Also, discussions are typically normative in implying that Mode-2 is desirable to Mode-1, with few works emphasising their complementarity. For instance, Duru (2013) calls for combining three modes of knowledge production, each with various degrees of involving stakeholders, while Miller et al. (2011) address *epistemological pluralism* as necessary for building flexible and adaptive institutions.
- Using a **sociology of knowledge lens**, knowledge production is conceptualised in relation to power, hegemonic discourses or colonial legacy. For instance, Zingerli (2010) addresses *collaborative knowledge production* as a process for levelling out power differences that are embedded in global North-South partnerships. Others critique how the scientific vs. local knowledge dichotomy is loaded with a neoliberal discourse and call for *knowledge encounters* (Sletto and Nygren, 2015) or for the engagement of multiple *civic epistemologies* (Miller, 2005) as ways of decolonising marginalized perspectives and of counteracting hegemonic influences. In this context, knowledge production is (again) often used interchangeably with knowledge co-production and transdisciplinarity (Maiello et al., 2011).
- **In policy and governance literature** we encounter the narrower term of ***joint knowledge production*** (JKP). Hegger et al. (2012a) specifically situate JKP between science and policy, while contrasting it to the term *knowledge co-production*, which, they claim, alludes too much to the co-production of social order. Instead, JKP is a deliberative process taking place within specific projects, where the main actors involved are scientists and policy-makers, and others participate occasionally (Hegger and Dieperink, 2014; Hegger et al., 2012a). As JKP happens at the micro-level of projects or initiatives, it may also be a manifestation of higher-order processes, such as participatory action research, transdisciplinarity, or post–normal science (Hegger et al., 2012b, p. 1051). Offermans and Glasbergen (2015) orient JKP towards the notion of partnerships, explicitly opening it beyond policy-makers and scientists, e.g. to NGOs and businesses, to include other knowledge types than just scientific. Finally, Rist et al. (2007) mention JKP emphasising interactions between experts and local actors.
- **Knowledge production in *transdisciplinary research*** refers to a collaborative process, where the emphasis is put on the dichotomy between academic and non–academic actors, as well as on its various stages: e.g. problem definition, collaboration, mutual learning, and integration (Payne and Shepardon, 2015; Angelstam et al., 2013a). The aim of such a process is to create knowledge that can inform action, by balancing academic standards with societal relevance. The quality of the process is deemed important, and tacit outcomes and "value rationalities" of actors are also appreciated (Polk and Knutsson, 2008).

Aside from the above, knowledge production is sometimes explicitly used interchangeably with *knowledge co-production* (Popa et al., 2015), or *knowledge generation* (Rametsteiner et al., 2011), while other times it is subsumed to *co-production* (Wyborn, 2015), *knowledge exchange* (Cvitanovic et al., 2015) or *knowledge integration* (Knutsson, 2006). Lastly, some see it as a process embedded in management frameworks, e.g. integrated water resource management or adaptive management (Medema et al., 2008).

4.3.2. Knowledge co(-)production

In a review on co-production, Wyborn (2015) distinguishes between: (a) works in science and technology studies, where co-production is a lens for examining how science shapes and is shaped by the social order in which it operates, with a focus on the power-knowledge interplay (*sensu* Jasanoff, 2010); and (b) instrumental uses of the term accounting for collaborative processes between actors that aim to solve specific (policy) problems. The latter dominates in sustainability science. An exception is Watson (2013) who critiques adaptive co-management for overlooking power relations in Western-Indigenous collaborations and suggests that such concerns be explicitly addressed. We add further granularity to Wyborn's (2015) distinction, by identifying two levels at which the instrumental model of knowledge co–production is discussed.

- First, *knowledge coproduction* refers to *institutional* processes of bringing together various actors and their knowledge, discussed in relation to co–management theory and adaptive governance (Armitage et al., 2011). The importance of learning in institutional networks, as well as of *bridging and boundary organizations* is emphasized. The assumption is that a diversity of perspectives provide a more complete picture of the whole system and can enhance the adaptive capacity of the social(-ecological) system (Reyers et al., 2015).
- Second, *knowledge coproduction* is project-based and refers to joint work of stakeholder groups on tangible reports and research (see e.g. Davidson-Hunt et al. (2013). Co-production in this case has a short time horizon and can directly contribute to a community's adaptive capacity.

Most papers, however, do not conceptualise or operationalise *knowledge co–production* at all, nor do they link it to governance theories or models. Instead, the term is used in a common sense form, taking a constructivist rather than positivistic view on knowledge (Schneider et al., 2009), and implying simply collaboration between actor groups (Butler et al., 2016; Risvoll et al., 2014; Cornell et al., 2013). For instance, it may refer to the joint creation of art by elders and youth (Rathwell and Armitage, 2016), or to community-based monitoring processes involving scientists and residents of the Arctic (Johnson et al., 2015).

4.3.3. Knowledge integration

Debates surrounding processes of ***knowledge integration*** span various fields and there is wide agreement that integration is desirable. Just one paper in our dataset suggests the opposite: Gray et al. (2012) argue that while integration leads to a more complete picture of a social–ecological system (increasing structural knowledge of variables and subsystems), it also makes understanding the mechanisms more difficult (decreasing precision in understanding).

Despite the general consensus on the desirability of integration, it is hard to find coherent conceptualisations of this process. **A first group of studies discusses what and how to integrate. Three options emerge here** depending on whether the elements to be integrated are regarded as of equal value or not.

- A first option sees **integration as *renewing*** a knowledge system by adding new knowledge or information to it. For instance, the integration of indigenous and Western scientific knowledge is often framed as a renewal and improvement of the latter using the former, thus pointing to an implicit relationship of subordination between the two (Bohensky and Maru, 2011; Butler et al., 2012). Similarly, in agriculture, Eidt et al. (2012) conceptualise knowledge integration as a *renewal process* happening over time via permanent flows of knowledge between farmers and developers of new technologies, and to be observed at the level of the farm as a mix of traditional and new practices.

- A second option conceptualises **integration as *bringing together*** and synthesising various knowledge pieces into something new. This option recognizes the importance of power relations between various groups of actors, as well as of the learning aspects fostered in formal and informal participatory processes (Stepanova, 2015). For Shiroyama et al. (2012) knowledge integration is a way of dealing with uncertainty and risk and consists of coordinating across policy sectors and groups of stakeholders. This model of integration does not usually discuss specific practices, such as how groups should be selected, nor how values and stakes should be accounted for. Exceptions are methodological and theoretical studies in transdisciplinarity research that do provide specific practical tools for fostering integration (Scholz et al., 2015a).
- A third option sees integration as **bringing diverse knowledge *into decision-making***. For instance, Gray et al. (2012) consider how integrating stakeholder knowledge into natural resource governance creates flexibility and adaptability in the social-ecological system at stake. The knowledge management community also focuses on the solutions or decisions that result from social interactions. Knowledge integration, in this context, requires effective knowledge flows throughout the organization (and sometimes also with external stakeholders) and leads to innovation (Sandhawalia and Dalcher, 2015; Sindakis et al., 2015).

These perspectives resemble three ways of bringing IK and WSK together, as summarized by Rathwell et al. (2015): a) IK and WSK as enriching each other, but retaining their independent pathways; b) creating new and hybrid knowledge through co-production; and c) jointly forming a multiple-evidence base for decisions.

A second group of works critically reflect on the nature of integration in participatory processes involving multiple stakeholders.

- **Integration as a process** moves from the observation that what constitutes "knowledge" differs from project to project, hence the focus should not be on evaluating the results of participation, but on designing a process which creates the necessary conditions for reflexivity and negotiating perspectives. Along these lines, Raymond et al. (2010), for instance, propose a framework with several questions and factors to be considered in project teams.
- Scholars looking at **integration as outcomes** look at concrete results of a participatory process. As an example, Soria-Lara et al. (2016) review and test interventions and mechanisms of integrating knowledge within processes of environmental impact assessment (EIA) by comparing self-reported perceptions of participants in ex-ante and ex-post surveys. Similarly, others see knowledge integration as a consequence or effect of other processes, such as boundary work (Robinson and Wallington, 2012) or collaborative research (Cullen-Unsworth et al., 2012; Fernández-Giménez et al., 2006).
- Many publications **combine both** perspectives, for instance Evans et al. (2011) looking at the integration of local and research–based knowledge, in the context of adaptive marine governance. Beyond the process/outcome dichotomy, Knutsson (2006), proposes that knowledge integration be thought of in terms of its *uses*, *purpose*, *forms* and *degree* accomplished. With respect to where knowledge integration is *used*, they differentiate between the production, dissemination and application of knowledge and assert that most literature focuses on the production use of integration, to the detriment of the other two.

A last point is that many conceptualisations include elements from both groups above: e.g. in co-management literature, knowledge integration is a *process* of *bringing together* stakeholder groups, alongside knowledge sharing and interpretation, collective learning and reflexivity (Linke and Bruckmeier, 2015; Armitage et al., 2011; Baival and Fernández-Giménez, 2012; Robinson and Wallington, 2012).

4.3.4. Knowledge management

Most publications on ***knowledge management*** (KM) and sustainability belong to fields such as engineering, or architecture and infrastructure. Sustainability issues are mentioned in relation to hazard mitigation, transportation logistics or supply chain management. Following Nonaka (1994), *knowledge* is seen as a flow of structured information, while *management* is required to make the right information available to the right people at the right time (Preuss and Córdoba-Pachon, 2009; Yang et al., 2015). As such, *knowledge management* is a strategic system for organizational learning (Ayuso et al., 2011), encompassing various phases (Evangelista and Durst, 2015; Wu and Haasis, 2013; Yang et al., 2015; Meese and McMahon, 2012). Here, we review works where knowledge management and sustainability literatures meet.

- Contributions **embracing standard KM literature** discuss such processes within the context of organizations or firms, either as means for improving overall sustainability practices (Evangelista and Durst, 2015; Wu and Haasis, 2013) and CSR performance (Preuss and Córdoba-Pachon, 2009; Siltaoja, 2014), or for increasing the capacity of these organizations to innovate for sustainability (Sindakis et al., 2015; Yang et al., 2015; Ayuso et al., 2011). Various enablers for effective knowledge management are also often addressed, for instance: leadership and the organizational culture, stakeholder integration (Ayuso et al., 2011; Yang et al., 2015), the elicitation of tacit knowledge (Sandhawalia and Dalcher, 2015), or the creation of communities of practice (Preuss and Córdoba-Pachon, 2009).
- Further contributions **combine elements of KM theory with other approaches**. For example, in an article on knowledge for resource dilemmas, Blackmore (2007) lists knowledge management as one among different learning theories or models. He distinguishes among three generations of knowledge management: one focused on knowledge sharing and transfer, another emphasising knowledge creation, and a third revolving around constructivist ideas and notions of complexity (Blackmore, 2007, p. 522). In doing so, he implies knowledge management as an umbrella-concept for various perspectives on knowledge flows across society. Another illustration is offered by Offermans and Glasbergen (2015): in their evaluation framework for JKP processes, *knowledge management* is a criterion that can take values from "fully managed" to "no management" and signals the degree of deliberate intervention on altering knowledge flows.
- Finally, several scholars propose that KM is taken up as a **formal process into other fields of application**. Schut et al. (2014) argue that researchers ought to assume knowledge management roles in their work, which include activities such as knowledge brokerage, knowledge packaging and dissemination. In the context of adaptive management, Rogers et al. (2000) underline the role of knowledge management in creating learning organizations, a branch described as strategic adaptive management (SAM). Lastly, applied to post-disaster housing reconstruction, knowledge management is a formal strategic process for assessing decision-making in projects and for eliciting and systematising lessons learned (Hayles, 2010).

4.4. Knowledge for and through learning

This group of articles looks at the **dynamics of knowledge in a system**, in relation to learning. Knowledge may be regarded as input to learning, the outcome thereof, or both. Learning is how knowledge as entity is updated via process. Learning is a vast theoretical field in itself, which is why we treat it separately from other knowledge processes discussed above. It takes many forms, e.g. *social learning, policy learning, single-, double-, triple-loop learning, experiential learning, participatory action learning* etc. (see Appendix C1), but also includes concepts such as *education for sustainable development* or *social information*. We reflect here on the most frequently encountered concepts in our dataset: *social learning* and *sustainability learning*, respectively.

4.4.1. Social learning

By far the most frequently employed knowledge-related construct in our dataset is ***social learning***, with diverse interpretations of the term (Reed et al., 2010; Rodela, 2011). Reed et al. (2010) derive two meanings of social learning either as:

- **Individual learning** that is influenced by social norms (Bandura, 1977), or as
- Process of **social change**, often conflated with stakeholder participation.

Reed et al. (2010) recommend to distinguish between the conditions that facilitate social learning (in individuals as well as wider societal groups), the process itself, and its outcomes. A systematic review one year later identifies three research perspectives on social learning within natural resource management literature (Rodela, 2011): an individual-centric (changes in participants); a network-centric (changes in practices and relationships); and a system centric perspective (changes in institutional setting and relevant policy practices). We use these insights to refine the two conceptualisations suggested by Reed et al. (2010) in Table 5. Subsequent reviews build upon this work to further delineate the concept and its implications (Ensor and Harvey, 2015; Cundill et al., 2014), with Medema et al. (2014) particularly discussing *multi-loop social learning* within land and water governance.

Finally, with respect to the link between knowledge and social learning, scholars often highlight the inseparability of processes of "co-creation" (understood as participatory co-production) or *integration* (*sensu* "bringing together") and social learning (e.g. Ensor and Harvey, 2015; Schneider et al., 2009). Others emphasize the importance of tacit and experiential knowledge in connecting action and experimentation processes so as to stimulate social learning (Hagemeier-Klose et al., 2014) or highlight the importance of capacity building for continuous social learning as part of crafting usable knowledge (Clark et al., 2016).

4.4.2. Sustainability learning

Not many papers employ the concept of ***sustainability learning***, but those that do are quite homogenous in their understanding of it. We address it here because it draws on social learning, and brings to the front a normative dimension of such processes.

- Tàbara and Pahl-Wostl (2007) point out that most social learning discussions do not capture *what* is to be learned. Instead, *sustainability learning* could delineate a type of social learning that aims to increase the ability of people and institutions to identify long-term threats to social-ecological systems, and to prepare for managing and adapting to them. Other scholars employing the concept simply build upon this interpretation in their theoretical or empirical work (Polk, 2011; Hansmann, 2010). Notably, Hansmann (2010) further clarifies the concept, by emphasising its multi-level aspect comprising of learning of individuals, groups, organizations and of society at large
- In earlier work, Scholz et al. (2006) had already referred to "planning and learning processes for sustainable development" as *sustainability learning*, to be facilitated by transdisciplinarity, but had not further conceptualised the term as such. Lastly, a slightly different interpretation stems from educational sciences, where *transformative sustainability learning* refers to a pedagogy where deep inner changes are triggered in the participants, spanning across cognitive to emotional and normative dimensions (Sipos et al., 2008).

4.5. Knowledge at interfaces

This fourth approach takes a macro-level perspective on knowledge in society and preoccupies itself with broad questions on how knowledge is created, to what purposes and with what degree of validity. Publications inquire about the interactions between societal spheres or focus on methodological issues in the societal acquisition of knowledge (Appendix C1, "interfaces" and "research modes" categories). In both cases, this entry point thus pertains to boundaries between multiple systems. We call these ***interfaces***, and we ascribe here constructs such as *knowledge-to-action*, *science-policy, research-policy, science-practice* etc., but also *boundary work*, *bridging and boundary organizations*, *boundary objects*, *transdisciplinary research, action research* etc. We retain for further analysis the *knowledge-to-action* and *the science-policy/research-policy* interfaces.

4.5.1. Knowledge-to-action

Literature on translating knowledge into action often departs from experiences in the health sector which followed a *linkage-and-exchange* model of connecting researchers to policy-makers (van Kerkhoff and Szelezák, 2016). In sustainability science, this model is taken one step further as scholars call for a systems perspective, and knowledge is interpreted in a co-productionist framework (at the level of "social order", as discussed above). Also, a central question is how to create knowledge which is "usable" for realising desired outcomes (Clark et al., 2016). We identify two main conceptualisations of knowledge-to-action.

- The first perspective emphasizes the role of actors and networks in bringing knowledge to decision arenas. For instance, Muñoz-Erickson (2014b) define knowledge-action (K-A) systems as "formal and informal networks of individuals and organizations in which knowledge, ideas, and strategies for sustainability are being produced, evaluated and validated" (p. 2). Many K-A systems co-exist and they interact in different configurations, and across various cultures, epistemologies and political dimensions (Muñoz-Erickson, 2014a). Similarly, van Kerkhoff and Szelezák (2016) depart from the notion of knowledge systems to underline the actor-centred nature of this interface, with knowledge embodied by individuals and evolving through group processes.
- A second perspective brings brokerage and boundary work to the forefront (Wyborn, 2015; Talwar et al., 2011). While not always explicating the underlying mechanisms, the idea is that knowledge can be linked to action through appropriate mediating institutional structures (Cash et al., 2003; Shanley et al., 2009; Talwar et al., 2011) or via policies (Berbés-Blázquez et al., 2014). Participation and learning are emphasized (Cornell et al., 2013; Shaw and Kristjanson, 2014), with scientists and researchers playing a central role in facilitating this link (Shanley et al., 2009; Clark et al., 2016; Charron, 2012; Berbés-Blázquez et al., 2014).

4.5.2. Science-policy/Research-policy

The ***science-policy*** interface is also concerned with knowledge in its broader societal context. Gulbrandsen (2008) identifies three perspectives for examining this interface: a first one considers that science is providing verifiable facts to policy makers who will not dispute their certainty and will take action; a second, political-institutional approach, considers that knowledge and science cannot be separated from politics; third, a political economy approach assumes that policy implementation of knowledge will depend on whether benefits and costs are broadly distributed. Our analysis shows that how scholars frame the science-policy interface and what solutions they propose largely depends on which of these perspectives they implicitly take.

- The original conceptualisation presumes **a "gap" which needs to be "closed"**, often through work conducted by so-called *bridging* or *boundary organizations* (Sternlieb et al., 2013; Cash et al., 2003; Fogel, 2005; Heland et al., 2014). This view begs the question of how to make science relevant and typically looks at processes between scientists and policy-makers, occasionally also including other types of actors or the broader public. Hickey et al. (2013), for instance, examined practitioners' views on how exchanges between scientists and policy-makers *within* governmental agencies might be improved. Results indicate that opportunities for knowledge sharing and transfer are linked to social capital understood as trust, generalized reciprocity and social connectivity within the organization. Similarly, Crona and Parker (2012) empirically showed that more interactions with scientists within bridging organizations lead to better knowledge utilisation in policy for adaptive resource governance. Sindakis et al. (2015) suggest that the science-policy gap can be closed by knowledge management activities. Lastly, Pihlajamäki and Tynkkynen (2011) discuss the need for transparency related to knowledge–policy interactions through deliberations on neutrality and objectivity.

- A more recent conceptualisation, which predominates in our dataset, follows van Kerkhoff and Lebel (2015) who call for a move away from the idea of a gap, towards a **coproduction perspective** where the interplays between science and governance are recognized (Hegger and Dieperink, 2014; Hegger et al., 2012a, 2012b). Bremer and Glavovic (2013) argue that this interface needs to be regarded as a "governance setting", where knowledge and values are co-constructed and inclusive, however without compromising on quality of process and of product. In a similar fashion, Schut et al. (2014) put forward the concept of *boundary arrangements* to discuss that there are multiple stakeholder–stakeholder interfaces, which need to be considered independently: research–government, research-private sector, research-civil society. Last, Vogel et al. (2007) regard the science-policy as included in a broader science-practice interface where effective engagement requires various types of arrangements and networks, some stable over longer period of times, while others dismantled soon after a policy process.

5. Discussion

Our review indicates that, while the word *knowledge* is increasingly used, it is almost never the main concept of investigation as such. Here, we attempted to gain insights about what is meant by knowledge in sustainability science by looking at the broad variety of related terms in use. Many publications touch upon several concepts, but usually only one or two are specified, and with little consideration to conceptualisations from adjacent fields or other authors. Depending on their disciplinary background, scholars tend to have their preferred knowledge-related themes, terms and even journals. While this may be appropriate to a certain extent, we suggest that it also leaves blind spots, which might be filled by referring to other perspectives (RQ1).

With respect to the degree of convergence of different conceptualisations (RQ2), we emphasize that, if we want to advance our understanding of how knowledge can contribute to societal change, we ought to put more effort into developing a shared terminology. Our analysis suggests that those concepts for which the scholarly community has managed to precisely articulate shared meanings in the research process, such as *joint knowledge production* or *sustainability learning*, lend themselves more easily to replicable empirical research and theory-building. Recent advances of the debates on *social learning* within sustainability science (e.g. Ernst, 2019, Siebenhüner et al., 2016) illustrate how clear and shared concepts can be stepping stones towards more robust empirical research. Where disagreement persists, however, it would be important to clarify the differences and the epistemological stances that may cause them. Precision is appropriate when operationalising a concept (Jacobs 1999), as it may facilitate joint work across disciplines and societal spheres, thus contributing to transdisciplinary and co-production processes.

In this review, we propose to approach knowledge in sustainability science through various entry points (RQ3), none of which is supposed to exhaust the complexities of the topic as a whole. Rather than assuming that these multiple angles are incompatible, we suggest to conceive of them as interconnected (Fig. 5). Knowledge has been described via its attributes as a distinct object (*entity*) separated from process, it has been studied as embodied and embedded in individual or group actions (*process*), or regarded as the dynamic by which entity is actualized through process (*learning*). It has also been analysed holistically as a *system* comprising of all the above mentioned elements and their interrelations. Lastly, it has been examined as a boundary between various societal systems, including knowledge production systems themselves (*interface*).

Considered together, these five entry points hint to a systems take on knowledge that tacitly permeates sustainability science, where its various elements are seen as inter-related and interacting. Scholars often interweave these five perspectives in different ways, as they move across various scales and contexts, from the micro-level of group decision–making, to the macro-level of how science is shaped by society and vice-versa. For instance, knowledge co-production may be analysed not primarily as a process, but also in the context of science-policy interfaces, while traditional ecological knowledge may be explicitly examined as a knowledge system rather than as an entity, and within a Mode-1/Mode-2 debate. In addition, different uses of the same concept may have ramifications towards other concepts or entry points. For example, the instrumental model of knowledge coproduction at project level is close to understandings of JKP (both are situated at the micro-level), while the social critique model of knowledge coproduction is rather connected to the co-productionist perspective of the science-policy interface and to understandings of knowledge systems as ways of knowing (macro-level interpretations).

Fig. 5 is one possible way of illustrating the interconnections of various perspectives on knowledge embedded in the literature, by using the language of systems thinking. By exposing and organising this diversity, we hope to start a dialogue on what a comprehensive understanding of knowledge might entail, and to contribute towards more rigorous theory building on the potential of knowledge as capacity to act (Stehr and Grundmann, 2005). While our review is especially directed at researchers and is limited to scientific literature, we do not posit science to be the only way to learn something about how and when knowledge leads to action. Quite the opposite, we recognize research as one out of a larger set of tools, so insights from other domains, from public administration to practice, will play equally essential roles in contributing to sustainability.

Our dataset includes publications up until late 2016. Since then, key studies have further investigated the nature of knowledge and its interplay with action, along the lines captured here. For instance, some works have emphasized the importance of knowledge co-production (Turnhout et al., 2020; Norström et al., 2020; Schneider et al., 2019; Wyborn et al., 2019; Miller and Wyborn, 2018; Frantzeskaki and Rok,

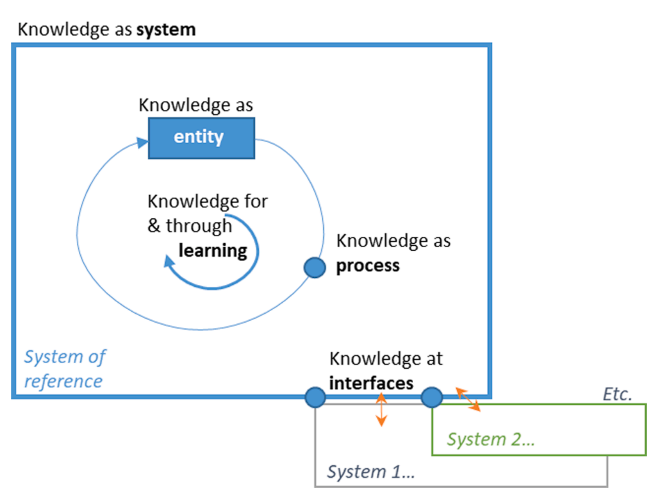

Fig. 5. Interconnections of five entry points to knowledge.

2018), while others focus on knowledge systems in applied contexts (Chapman and Schott, 2020; Muñoz-Erickson et al., 2017; Tengö et al., 2017), or theorise actionable and action-oriented knowledge (Arnott et al., 2020; Caniglia et al., 2020; Dewulf et al., 2020; West et al., 2019). A few reviews systematically address knowledge in specific bodies of literature, such as knowledge management (Sanguankaew and Vathanophas Ractham, 2019; Martins et al., 2019) or (social) learning (Ernst, 2019; Siebenhüner et al., 2016). We complement these studies by eliciting an integrated way of thinking about knowledge which spans across a vast scholarly landscape and tries to capture the complexities and ambiguities of how knowledge has been talked about and utilised in the literature. Future studies could build upon our work and corroborate the evidence on the *role* of knowledge for sustainability by accounting for the various aspects discussed here.

6. Conclusion

This review is a first attempt to comprehensively map and organise uses of the notion of knowledge and related concepts in sustainability science. By providing an overview of the concepts encountered, as well as by organising them along five entry points, this work paves the way towards better science for understanding the role of knowledge for societal change towards sustainability. Knowledge alone will not be enough to solve the complex challenges humanity is facing; many other variables (interests, values, path dependencies etc.) will affect the extent of our actions. However, knowledge remains an essential part of processes of decision-making and change which deserves to be rigorously studied. Our work contributes to rescuing this term from becoming a buzzword and to advancing this research agenda.

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CRediT authorship contribution statement

Cristina I. Apetrei: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Writing - original draft, Writing - review & editing, Visualization. **Guido Caniglia:** Conceptualization, Writing - original draft, Writing - review & editing. **Henrik Wehrden:** Conceptualization, Methodology, Validation, Resources, Writing - original draft. **Daniel J. Lang:** Conceptualization, Methodology, Validation, Resources, Writing - original draft, Writing - review & editing, Project administration, Funding acquisition.

Declaration of Competing Interest

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

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Appendix A: Existing reviews on knowledge concepts in sustainability science

To this date, there is no comprehensive overview or systematic comparative discussion of knowledge-related concepts in sustainability science.

Existing reviews and syntheses have either focused on one concept at a time, or narrowed their scope to particular contexts. For instance, Bohensky and Maru (2011) reviewed the literature on *integrating indigenous and scientific knowledge* with respect to fostering resilience, while Bardsley and Sweeney (2010) reported on methods for *knowledge generation* in relation to adaptation. Others stayed within the perspective of a certain field: Bremer and Glavovic (2013) discussed *knowledge mobilisation* for integrated coastal management, while Meese and McMahon (2012) addressed *knowledge sharing* within civil engineering. Although such papers offer their own definitions of the concepts employed, they do not contrast them to other uses, nor do they reflect on how or why their terminology differs from that of other authors dealing with similar phenomena.

The problem of divergent conceptualisations of the same term is recognized by many authors, and a few attempts at bringing together or critically comparing definitions do exist, particularly for concepts that are already vastly utilised. Rodela (2011), for example, reviews how *social learning* is understood in the resource management literature and identifies three overarching research perspectives. Tosey et al. (2012) offer a historical account of the origins of the concept of *triple-loop learning*, while Davis and Ruddle (2010) review the analytical and empirical uses of the notions of *indigenous ecological knowledge, traditional knowledge* and *local ecological knowledge* in natural resource management. Hessels and van Lente (2008) provide a critical analysis of the *new production of knowledge*, by discussing Gibbons' (1994) proposition of a Mode-2 type of science in relation to various alternative approaches. Lastly, Fazey et al. (2013) summarize key themes of interest surrounding *knowledge exchange* for environmental management to suggest a research agenda for the future. In this pursuit, they contrast the meanings of several terms, such as *knowledge generation, knowledge storage, coproduction of knowledge or brokerage of knowledge*, and ascribe them all under the umbrella of *processes of knowledge exchange*.

A final category of reviews that we identified abstracts various conceptualisations to archetypical perspectives or models. In their analysis of *knowledge to action* linkages, Best and Holmes (2010) classify existing conceptualisations in health sciences within three broad classes of models: linear, relationship and systems models. Within the context of sustainable development, van Kerkhoff and Lebel (2006) do a similar exercise, but provide a finer granularity to their classification, by identifying: two conventional models, the *trickle-down* and the *transfer and translate* model, as well as four counter-models, specifically the *participation, integration, negotiation and learning* models, respectively. Finally, Funtowicz (2006) also provides a useful typology of models of science-policy interfaces, namely: *the perfection / modern legitimation* model, the *precautionary* model, the *framing* model, the *demarcation* model, and the model of *extended participation* (corresponding to post-normal science). What is notable about these latter examples is that their scope moves from narrow concepts to broader overviews of how knowledge is linked to decisions and actions. And yet, linkages between concepts referring to micro-processes, such as knowledge sharing in a group, and those pertaining to macro-processes, such as the use of scientific research in policy making, remain largely unaddressed.

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Appendix B: Details on review protocol & methodology

B.1. Search string

TITLE-ABS-KEY (("knowledge *produc*" OR "knowledge *creat*" OR "knowledge *mak*" OR "knowledge *generat*" OR "knowledge *manag*" OR "knowledge *use*" OR "knowledge *diffus*" OR "knowledge disseminat*" OR "knowledge *integrat*" OR "knowledge system*" OR "social learning" OR "sustainability learning" OR "policy learning") AND ("sustainab* transformation" OR "sustainab* transition" OR "sustainable development" OR "environmental change" OR "social-ecological" OR "human-environment*" OR "environmental governance" OR "sustainab* governance"))

B.2. Screening of abstracts phase

Exclude papers if any of the following:

Criterion	Explanation
False positive	Title, abstract and keywords don't actually contain search terms from both sets, but it is rather a database notation mistake, or the automatically assigned keyword is wrong.
No knowledge or learning related concept as primary or secondary research object of the article	Focus of the article is on something completely different and a knowledge-related term might have been coincidentally mentioned (e.g. studies on diabetes or from health sciences, or evolutionary biology articles).
No sustainability / social-ecological / human-environment interactions focus	For instance, the word sustainability is used with the meaning of enduring, such as "sustainability of digital ecosystems".
No abstract in the database	Self-explanatory
No institutional access to full-text	Self-explanatory

B.3. Eligibility/selection of papers phase

Assess full-text of papers and assign them to one of the following "Result" categories, based on whether they meet **at least one** of the corresponding criteria mentioned below. Please note that fulfilling a criterion in the "in" category does not preclude the article from being assigned into the "in-depth" category, should a superior criterion also apply.

Result	Criterion	Short name of criterion
In-depth analysis (= a lot of information can be extracted from this article regarding knowledge-related concepts)	conceptualisation of knowledge/learning or knowledge related processes (production etc.), including conceptual frameworks etc.	conceptualisation k/l
	clear description or review of knowledge-related concepts and theories (significant section in the paper)	theory reference
	conceptualisation of linkages between knowledge/learning and sustainability transformation	conceptualisation linkage
	empirical evidence of the contribution of knowledge/learning to sustainability transformation	empirical evidence
	procedural description of the contribution of knowledge (types) or learning processes to participatory decision making	procedural description
In (= minimal information can be extracted and articles in this category are saved in our database for future work, but not included in this study)	enumeration of knowledge types	knowledge types
	mentioning of knowledge-related processes	process types
	mentioning of information, knowledge or learning as variables in broader conceptual frameworks for the analysis of social-ecological systems / decision situations / institutions etc. (e.g. Ostrom SES framework), but no further specification	in framework
	definition of knowledge/learning or a related concept	definition
	conceptual distinctions knowledge/learning vs. e.g. data, information, mental maps, values, opinions etc.	conceptual distinctions
	claim of link between knowledge/learning and transformation (based on literature or experience, but without clear evidence or argumentation)	linkage implied
Out (= no further analysis or coding to be done)	call for giving attention to the role of knowledge/learning, with no conceptualisation at all	call for
	other inadequacies not captured in screening phase (false positive, search strings have different meaning than intended etc.)	not relevant

B.4. Inflation-adjusted number of publications

Data for **article type** (according to our coding) **per year of publication** for 276 papers analysed in-depth:

Year of publication	Conceptual	Conceptual/Empirical	Empirical	Review	TOTALS
1994	1	0	0	0	1
1995					0
1996					0
1997					0
1998					0
1999	0	0	0	1	1
2000	0	2	0	0	2
2001					0
2002	0	0	1	0	1
2003	0	1	0	1	2
2004	0	2	1	1	4
2005	0	0	4	0	4
2006	3	3	2	0	8
2007	4	3	4	0	11
2008	2	4	8	1	15
2009	3	2	7	2	14
2010	4	5	9	3	21
2011	4	8	11	3	26
2012	2	4	14	5	25
2013	9	7	18	6	40
2014	6	7	18	4	35
2015	9	13	16	5	43
2016	2	4	14	3	23
				TOTAL	276

Data for **total** publications **between 1995** and **2016** on topics related to sustainability and the environment.

Source: Web of Science / 2019

Search string*:* TS (theme) = “environ*” OR “sustain*”; no further refinement to categories

Publication Years	Records	% of 1888508
1995	34887	1.847
1996	37538	1.988
1997	39567	2.095
1998	41713	2.209
1999	44139	2.337
2000	47282	2.504
2001	48424	2.564
2002	51924	2.749
2003	57247	3.031
2004	62221	3.295
2005	67973	3.599
2006	74448	3.942
2007	80845	4.281
2008	90582	4.796
2009	98666	5.225
2010	105179	5.569
2011	116160	6.151
2012	126231	6.684
2013	137373	7.274
2014	146202	7.742
2015	181523	9.612
2016	198384	10.505
(0 Publication Years value(s) outside display options.)		
(0 records (0.000%) do not contain data in the field being analysed.)		

Baseline year *chosen:* 2002

Inflation-adjusted number of publications on knowledge topics (relative to baseline year) was calculated with the following formula:

The results are shown in the table below and they inform the line in Fig. 3:

$$adjusted\ knowledge\ publications\ in\ year\ X = total\ knowledge\ publications\ in\ year\ X\ \times \frac{total\ publications\ in\ baseline\ year}{total\ publications\ in\ year\ X}$$

	Inflation-adjusted number of knowledge publications (baseline year = 2002)
2002	BASELINE YEAR
2003	2
2004	3
2005	3
2006	6
2007	7
2008	9
2009	7
2010	10
2011	12
2012	10
2013	15
2014	12
2015	12

Appendix C: Supplementary data

C.1. Overview of 148 semantic constructs, 75 concepts and 12 selected concepts, grouped in 9 categories

Knowledge (general	TOTAL = 30
knowledge dynamics	3
knowledge resource(s)	1
mental model(s)	1
*knowledge (general)**	4
knowledge and information	2
power and knowledge	1
social information	1
knowledge validation	1
evidential cultures, formative publics	1
prior related knowledge	1
schemas	1
collective memory	1
corporate memory	1
knowledge scales	1
useful knowledge	1
*knowledge processes (generic)**	1
*knowledge interactions at different scales**	1
*knowledge claims**	1
*evidence**	1
*knowledge and knowing**	1
*argumentation skills (related to: knowledge types)**	1
*knowledge types (generic)**	1
*information processing vs. embodied cognition**	1
*expertise (in governance)**	1

Knowledge systems	TOTAL = 19
knowledge system(s)	9
environmental knowledge systems	1
agricultural knowledge systems	1
open knowledge system	1
traditional knowledge systems	1
human information and knowledge systems	1
dialogues of knowledge systems	1
evolution of knowledge systems	1
*knowledge systems: learning**	1
knowledge encounters	1
knowledge arena	1

Learning (general)	TOTAL = 32
learning network	4
learning outcome(s)	2
learning theory(-ies)	1
learning for change	1
learning for adaptation	1
learning effect(s)	1
*learning (generic)**	15
*learning function of adaptive management**	2
cognitive social learners (ABM)	1
learning platform	1
*learning in EIA**	1
*gaming as learning**	1
learning institutions	1

Knowledge processes	TOTAL = 109
knowledge production	27
knowledge integration	17
knowledge management	13
knowledge co(-)production	12
knowledge sharing	7
knowledge generation	5
knowledge utilization / use	5
knowledge exchange	4
knowledge bridging	3
knowledge creation	3
knowledge transfer	3
knowledge brokerage	2
knowledge dissemination	2
knowledge transmission	1
knowledge making	1
knowledge mobilisation	1
knowledge acquisition	1
processes (multiple together)	2

Interfaces	TOTAL = 30
knowledge to action	10
science-policy / research-policy	10
science-society / science-policy-practice	8
science-practice	2

Knowledge types	TOTAL = 55
traditional ecological knowledge / TEK	7
traditional knowledge	2
indigenous knowledge / IK	6
indigenous ecological knowledge / IEK	2
local knowledge	6
local ecological / environmental knowledge / LEK	4
Western / scientific knowledge	4
ecological knowledge	3
global (environmental / ecological) knowledge	3
normative / target knowledge+	1
transformative / transformation knowledge+	1
sustainability knowledge	1
system knowledge+	1
tacit knowledge	1
expert knowledge	1
navigators' knowledge	1
CSR knowledge	1
cadastral knowledge	1
traditional phenological knowledge	1
usable knowledge	1
foresight knowledge	1
social knowledge	1
transdisciplinary knowledge	1
sustainable knowledge	1
open knowledge	1
vernacular knowledge	1
*knowledge for sustainable development**	1

Learning types	TOTAL = 115
social learning	67
sustainability learning	7
policy learning	7
organizational learning	3
double-loop learning++	2
joint learning	2
collective learning	2
transformative learning	2
mutual learning	2
collaborative learning	2
single-loop learning++	1
triple-loop learning++	1
situated learning	1
experiential learning	1
individual learning	1
learning for sustainability	1
environmental learning	1
participatory action learning	2
real-world learning	1
learning to learn	1
from ecological learning to social learning	1
instrumental, intrinsic and social learning	1
operational learning	1
social and institutional learning	1
generative learning	1
project-based learning	1
*modes of learning (incl. learning by experimenting)**	1
*learning (from evaluations)**	1

Research modes	TOTAL = 22
transdisciplinary / TD research	11
mode(-)2	2
action research	2
inter(-)disciplinary research	1
participatory research	1
problem-oriented research	1
solutions-oriented research	1
coproductive capacity	1
community engaged research	1
co-research	1

Other	TOTAL = 32
education for sustainable development / ESD	7
boundary work	4
community(-ies) of practice	3
bridging organization(s)	2
boundary object(s)	2
boundary organization(s)	1
worldview(s)	1
participatory (process / plan / land use / polic*)*	7
civic epistemology	1
epistemic cultures	1
knowledge-based firms	1
electronically mediated interaction (collaboration)	1
*research partnerships**	1

(dark grey)	concepts selected for further qualitative specification in current review (12 MOST EMPLOYED)
(light grey)	concepts minimally engaged with in the literature (75 CONCEPTS)
+/++	concepts usually treated together
italics	*other semantic constructs*
*	*concepts not searchable (too generic)*
n	numbers represent publication counts coded under the respective concept

C.2. Knowledge-related concepts in focus in top 23 journals

Concepts (corresponding to identified objects of study) / Journal (see Legend below table)	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	TOTALS
NA	0	1	3	17	1	3	2	3	3	2	0	3	1	1	1	2	0	0	0	0	0	0	0	43
action research	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	2	0	0	1	0	0	1	6
boundary objects	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
boundary organizations	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
boundary work	0	0	0	1	0	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4
bridging organizations	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
collaborative learning	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
collective learning	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3
community of practice	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	3
double-loop learning	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	2
ecological knowledge	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	4
education for sustainable development / ESD	0	1	0	1	0	1	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	6
environmental learning	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
global knowledge	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	3
indigenous ecological knowledge	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
indigenous knowledge	0	0	0	3	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	5
interdisciplinary research	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
joint learning	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	3
knowledge bridging	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	1	7
knowledge brokerage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
knowledge coproduction	0	0	0	2	0	0	1	2	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	7
knowledge dissemination	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2
knowledge exchange	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	3
knowledge generation	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3
knowledge integration	0	1	1	2	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	1	0	0	9
knowledge making	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	2
knowledge management	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
knowledge production	4	0	0	3	0	1	0	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	13
knowledge sharing	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	4
knowledge system	0	2	0	5	0	0	0	2	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	12
knowledge to action	0	0	0	3	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	6
knowledge transfer	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
knowledge transmission	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
knowledge use	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2
knowledge utilization	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
kowledge integration	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
learning effects	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2
learning for adaptation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
learning for change	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	2
learning network	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	1	0	0	5
learning outcomes	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2
learning theories	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	3
local ecological knowledge	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	4
local knowledge	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3
mental models	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
mode2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2
mutual learning	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3
organizational learning	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
participatory research	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
policy learning	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
science-policy	1	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	6
science-practice	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2
science-society	0	0	0	2	0	0	0	2	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	6
situated learning	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2
social learning	1	0	3	17	0	1	2	4	0	1	1	1	2	1	0	0	0	0	0	0	0	0	0	34
sustainability knowledge	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1	3
sustainability learning	0	1	0	1	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	5
system knowledge; transformative knowledge; normative	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
traditional ecological knowledge	0	0	0	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4
traditional knowledge	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
transdisciplinary / TD research	1	1	1	0	0	0	0	1	0	3	0	1	0	0	0	1	0	0	0	0	0	0	0	9
transformative learning	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	2
Western or scientific knowledge	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2
TOTALS	8	8	9	82	7	11	9	23	5	7	12	13	13	7	7	13	6	3	5	4	8	6	5	

a	Ambio
b	Current Opinion in Environmental Sustainability
c	Ecological Economics
d	Ecology and Society
e	Environment and Planning C: Government and Policy
f	Environmental Education Research
g	Environmental Management
h	Environmental Science and Policy
i	Forest Policy and Economics
j	Futures
k	Global Environmental Change
l	International Journal of Sustainability in Higher Education
m	Journal of Cleaner Production
n	Ocean and Coastal Management
o	Proceedings of the National Academy of Sciences of the United States of America
p	Sustainability Science
q	Water Resources Management
r	Sustainability
s	Society and Natural Resources
t	Journal of Sustainable Tourism
u	Journal of Environmental Management
v	Environmental Conservation
w	Environment and Planning A

Appendix D: List of publications included in this review.

No.	Authors	Title	Year	Source title
1	Adams M.S., Carpenter J., Housty J.A., Neasloss D., Paquet P. C., Service C., Walkus J., Darimont C.T.	Toward increased engagement between academic and indigenous community partners in ecological research	2014	Ecology and Society
2	Adelle, C; Jordan, A; Turnpenny, J	Proceeding in parallel or drifting apart? A systematic review of policy appraisal research and practices	2012	Environment and Planning C-Government and Policy
3	Ahlborg, H; Nightingale, AJ	Mismatch Between Scales of Knowledge in Nepalese Forestry: Epistemology, Power, and Policy Implications	2012	Ecology and Society
4	Alessa L., Kliskey A., Williams P., Barton M.	Perception of change in freshwater in remote resource-dependent Arctic communities	2008	Global Environmental Change
5	Anderson M.D.C.	The role of knowledge in building food security resilience across food system domains	2015	Journal of Environmental Studies and Sciences
6	Angelstam P., Andersson K., Annerstedt M., Axelsson R., Elbakidze M., Garrido P., Grahn P., Jönsson K.I., Pedersen S., Schlyter P., Skärbäck E., Smith M., Stjernquist I.	Solving problems in social-ecological systems: Definition, practice and barriers of transdisciplinary research	2013	Ambio
7	Angelstam P., Elbakidze M., Axelsson R., Dixelius M., Törnblom J.	Knowledge production and learning for sustainable landscapes: Seven steps using social-ecological systems as laboratories	2013	Ambio
8	Angelstam P., Grodzynskyi M., Andersson K., Axelsson R., Elbakidze M., Khoroshev A., Kruhlov I., Naumov V.	Measurement, collaborative learning and research for sustainable use of ecosystem services: Landscape concepts and Europe as Laboratory	2013	Ambio
9	Armatas C.A., Venn T.J., McBride B.B., Watson A.E., Carver S. J.	Opportunities to utilize traditional phenological knowledge to support adaptive management of social-ecological systems vulnerable to changes in climate and fire regimes	2016	Ecology and Society
10	Armitage D., Berkes F., Dale A., Kocho-Schellenberg E., Patton E.	Co-management and the co-production of knowledge: Learning to adapt in Canada's Arctic	2011	Global Environmental Change
11	Audouin M., Preiser R., Nienaber S., Downsborough L., Lanz J., Mavengahama S.	Exploring the implications of critical complexity for the study of socialecological systems	2013	Ecology and Society
12	Axelsson R., Angelstam P., Myhrman L., Sädbom S., Ivarsson M., Elbakidze M., Andersson K., Cupa P., Diry C., Doyon F., Drotz M.K., Hjorth A., Hermansson J.O., Kullberg T., Lickers F.H., McTaggart J., Olsson A., Pautov Y., Svensson L., Törnblom J.	Evaluation of multi-level social learning for sustainable landscapes: Perspective of a development initiative in Bergslagen, Sweden	2013	Ambio
13	Ayuso S., Rodríguez M.Á., García-Castro R., Ariño M.Á.	Does stakeholder engagement promote sustainable innovation orientation?	2011	Industrial Management and Data Systems
14	Bacon C.M., Mulvaney D., Ball T.B., DuPuis E.M., Gliessman S.R., Lipschutz R.D., Shakouri A.	The creation of an integrated sustainability curriculum and student praxis projects	2011	International Journal of Sustainability in Higher Education
15	Baden D., Parkes C.	Experiential learning: Inspiring the business leaders of tomorrow	2013	Journal of Management Development
16	Baival B., Fernández-Giménez M.E.	Meaningful learning for resilience-building among Mongolian pastoralists	2012	Nomadic Peoples
17	Ballard H.L., Belsky J.M.	Participatory action research and environmental learning: Implications for resilient forests and communities	2010	Environmental Education Research
18	Bardsley D.K., Sweeney S.M.	Guiding climate change adaptation within vulnerable natural resource management systems	2010	Environmental Management
19	Barkin D.	Communities constructing their own alternatives in the face of crisis	2012	Mountain Research and Development
20	Barrios E., Delve R.J., Bekunda M., Mowo J., Agunda J., Ramisch J., Trejo M.T., Thomas R.J.	Indicators of soil quality: A South-South development of a methodological guide for linking local and technical knowledge	2006	Geoderma
21	Barth M., Michelsen G.	Learning for change: An educational contribution to sustainability science	2013	Sustainability Science
22	Beers P.J., Van Mierlo B., Hoes A.-C.	Toward an integrative perspective on social learning in system innovation initiatives	2016	Ecology and Society
23	Beheshti R., Ali A.M., Sukthankar G.	Cognitive social learners: An architecture for modeling normative behavior	2015	Proceedings of the National Conference on Artificial Intelligence
24	Beratan K.K.	A cognition-based view of decision processes in complex social-ecological systems	2007	Ecology and Society
25	Berbés-Blázquez M., Oestreicher J.S., Mertens F., Saint-Charles J.	Ecohealth and resilience thinking: A dialog from experiences in research and practice	2014	Ecology and Society
26	Berker T., Bharathi K.	Energy and buildings research: Challenges from the new production of knowledge	2012	Building Research and Information
27	Betsill M.M., Bulkeley H.	Transnational networks and global environmental governance: The cities for climate protection program	2004	International Studies Quarterly
28	Blackmore C.	What kinds of knowledge, knowing and learning are required for addressing resource dilemmas?: a theoretical overview	2007	Environmental Science and Policy
29	Blackstock K., Dunglinson J., Dilley R., Matthews K., Futter M., Marshall K.	Climate proofing scottish river basin planning - A future challenge	2009	Environmental Policy and Governance
30	Bleischwitz R.	Governance of sustainable development: Co-evolution of corporate and political strategies	2004	International Journal of Sustainable Development
31	Blewitt J.	Higher education for a sustainable world	2010	Education and Training
32	Bohensky E.L., Maru Y.		2011	Ecology and Society

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No.	Authors	Title	Year	Source title
		Indigenous knowledge, science, and resilience: What have we learned from a decade of international literature on "integration"?		
33	Boillat S., Berkes F.	Perception and interpretation of climate change among quechua farmers of bolivia: Indigenous knowledge as a resource for adaptive capacity	2013	Ecology and Society
34	Bolton D., Landells T.	Reconceptualizing Power Relations as Sustainable Business Practice	2015	Business Strategy and the Environment
35	Bootsma, MC; Vermeulen, WJV; van Dijk, J; Schot, PP	Added Value and Constraints of Transdisciplinary Case Studies in Environmental Science Curricula	2014	Corporate Social Responsibility and Environmental Management
36	Böschen S.	Modes of constructing evidence: Sustainable development as social experimentation-the cases of chemical regulations and climate change politics	2013	Nature and Culture
37	Brandt P., Ernst A., Gralla F., Luederitz C., Lang D.J., Newig J., Reinert F., Abson D.J., Von Wehrden H.	A review of transdisciplinary research in sustainability science	2013	Ecological Economics
38	Bremer, S; Glavovic, B	Mobilizing Knowledge for Coastal Governance: Re-Framing the Science-Policy Interface for Integrated Coastal Management	2013	Coastal Management
39	Brunet N.D., Hickey G.M., Humphries M.M.	The evolution of local participation and the mode of knowledge production in Arctic research	2014	Ecology and Society
40	Buenstorf G., Cordes C.	Can sustainable consumption be learned? A model of cultural evolution	2008	Ecological Economics
41	Bulkeley H.	Urban sustainability: Learning from best practice?	2006	Environment and Planning A
42	Burgos A., Páez R., Carmona E., Rivas H.	A systems approach to modeling Community-Based Environmental Monitoring: A case of participatory water quality monitoring in rural Mexico	2013	Environmental Monitoring and Assessment
43	Butler J.R.A., Bohensky E.L., Suadnya W., Yanuartati Y., Handayani T., Habibi P., Puspadi K., Skewes T.D., Wise R.M., Suharto I., Park S.E., Sutaryono Y.	Scenario planning to leap-frog the Sustainable Development Goals: An adaptation pathways approach	2016	Climate Risk Management
44	Butler J.R.A., Tawake A., Skewes T., Tawake L., McGrath V.	Integrating traditional ecological knowledge and fisheries management in the torres strait, Australia:The catalytic role of turtles and dugong as cultural keystone species	2012	Ecology and Society
45	Calvet-Mir, L; Riu-Bosoms, C; Gonzalez-Puente, M; Ruiz-Mallen, I; Reyes-Garcia, V; Molina, JL	The Transmission of Home Garden Knowledge: Safeguarding Biocultural Diversity and Enhancing Social-Ecological Resilience	2016	Society & Natural Resources
46	Campbell J.M.	The land question in amazonia: Cadastral knowledge and ignorance in Brazil's tenure regularization program	2015	Political and Legal Anthropology Review
47	Cash D.W., Clark W.C., Alcock F., Dickson N.M., Eckley N., Guston D.H., Jäger J., Mitchell R.B.	Knowledge systems for sustainable development	2003	Proceedings of the National Academy of Sciences of the United States of America
48	Castella J.-C., Bourgoin J., Lestrelin G., Bouahom B.	A model of the science-practice-policy interface in participatory land-use planning: Lessons from Laos	2014	Landscape Ecology
49	Castello L., Viana J.P., Watkins G., Pinedo-Vasquez M., Luzadis V.A.	Lessons from integrating fishers of arapaima in small-scale fisheries management at the mamirauá reserve, amazon	2009	Environmental Management
50	Charron D.F.	Ecosystem approaches to health for a global sustainability agenda	2012	EcoHealth
51	Clark W.C., Van Kerkhoff L., Lebel L., Gallopin G.C.	Crafting usable knowledge for sustainable development	2016	Proceedings of the National Academy of Sciences of the United States of America
52	Cleland D., Dray A., Perez P., Cruz-Trinidad A., Geronimo R.	Simulating the Dynamics of Subsistence Fishing Communities: REEFGAME as a Learning and Data-Gathering Computer-Assisted Role-Play Game	2012	Simulation and Gaming
53	Cochran, F; Brunsell, N; Cabalzar, A; van der Veld, PJ; Azevedo, E; Azevedo, R; Pedrosa, RA; Winegar, L	Indigenous ecological calendars define scales for climate change and sustainability assessments	2016	Sustainability Science
54	Colding J., Folke C., Elmqvist T.	Social institutions in ecosystem management and biodiversity conservation	2003	Tropical Ecology
55	Colvin J., Blackmore C., Chimbuya S., Collins K., Dent M., Goss J., Ison R., Roggero P.P., Seddaiu G.	In search of systemic innovation for sustainable development: A design praxis emerging from a decade of social learning inquiry	2014	Research Policy
56	Cooper, I	Transgressing discipline boundaries: is BEQUEST an example of 'the new production of knowledge'?	2002	Building Research And Information
57	Cornell S., Berkhout F., Tuinstra W., Tàbara J.D., Jäger J., Chabay I., de Wit B., Langlais R., Mills D., Moll P., Otto I.M., Petersen A., Pohl C., van Kerkhoff L.	Opening up knowledge systems for better responses to global environmental change	2013	Environmental Science and Policy
58	Cowell, R; Lennon, M	The utilisation of environmental knowledge in landuse planning: drawing lessons for an ecosystem services approach	2014	Environment and Planning C-Government and Policy
59	Crona B.I., Parker J.N.	Learning in support of governance: Theories, methods, and a framework to assess how bridging organizations contribute to adaptive resource governance	2012	Ecology and Society
60	Csurgó B., Kovách I., Kučerová E.	Knowledge, power and sustainability in contemporary rural Europe	2008	Sociologia Ruralis
61	Cullen-Unsworth L.C., Hill R., Butler J.R.A., Wallace M.	A research process for integrating Indigenous and scientific knowledge in cultural landscapes: Principles and determinants of success in the Wet Tropics World Heritage Area, Australia	2012	Geographical Journal

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No.	Authors	Title	Year	Source title
62	Cumming G.S., Olsson P., Chapin III F.S., Holling C.S.	Resilience, experimentation, and scale mismatches in social-ecological landscapes	2013	Landscape Ecology
63	Cundill G., Lotz-Sisitka H., Mukute M., Belay M., Shackleton S., Kulundu I.	A reflection on the use of case studies as a methodology for social learning research in sub Saharan Africa	2014	NJAS - Wageningen Journal of Life Sciences
64	Cvitanovic C., Hobday A.J., van Kerkhoff L., Wilson S.K., Dobbs K., Marshall N.A.	Improving knowledge exchange among scientists and decision-makers to facilitate the adaptive governance of marine resources: A review of knowledge and research needs	2015	Ocean and Coastal Management
65	Dangelo M.J., Brunstein J.	Social learning for sustainability: Supporting sustainable business in Brazil regarding multiple social actors, relationships and interests	2014	International Journal of Sustainable Development and World Ecology
66	Davidson-Hunt I.J., Idrobo C.J., Pengelly R.D., Sylvester O.	Anishinaabe adaptation to environmental change in northwestern ontario: A case study in knowledge coproduction for nontimber forest products	2013	Ecology and Society
67	Demaid A., Quintas P.	Knowledge across cultures in the construction industry: Sustainability, innovation and design	2006	Technovation
68	Devente J., Reed M.S., Stringer L.C., Valente S., Newig J.	How does the context and design of participatory decision making processes affect their outcomes? Evidence from sustainable land management in global drylands	2016	Ecology and Society
69	Diaz, S; Demissew, S; Carabias, J; Joly, C; Lonsdale, M; Ash, N; Larigauderie, A; Adhikari, JR; Arico, S; Baldi, A; Bartuska, A; Baste, IA; Bilgin, A; Brondizio, E; Chan, KMA; Figueroa, VE; Duraiappah, A; Fischer, M; Hill, R; Koetz, T; Leadley, P; Lyver, P; Mace, GM; Martin-Lopez, B; Okumura, M; Pacheco, D; Pascual, U; Perez, ES; Reyers, B; Roth, E; Saito, O; Scholes, RJ; Sharma, N; Tallis, H; Thaman, R; Watson, R; Yahara, T; Hamid, ZA; Akosim, C; Al-Hafedh, Y; Allahverdiyev, R; Amankwah, E; Asah, ST; Asfaw, Z; Bartus, G; Brooks, LA; Caillaux, J; Dalle, G; Darnaedi, D; Driver, A; Erpul, G; Escobar-Eyzaguirre, P; Failler, P; Fouda, AMM; Fu, B; Gundimeda, H; Hashimoto, S; Homer, F; Lavorel, S; Lichtenstein, G; Mala, WA; Mandivenyi, W; Matczak, P; Mbizvo, C; Mehrdadi, M; Metzger, JP; Mikissa, JB; Moller, H; Mooney, HA; Mumby, P; Nagendra, H; Nesshover, C; Oteng-Yeboah, AA; Pataki, G; Roue, M; Rubis, J; Schultz, M; Smith, P; Sumaila, R; Takeuchi, K; Thomas, S; Verma, M; Yeo-Chang, Y; Zlatanova, D	The IPBES Conceptual Framework - connecting nature and people	2015	Current Opinion in Environmental Sustainability
70	Dionnet M., Daniell K.A., Imache A., von Korff Y., Bouarfa S., Garin P., Jamin J.-Y., Rollin D., Rougier J.-E.	Improving participatory processes through collective simulation: Use of a community of practice	2013	Ecology and Society
71	Disterheft A., Azeiteiro U.M., Filho W.L., Caeiro S.	Participatory processes in sustainable universities – what to assess?	2015	International Journal of Sustainability in Higher Education
72	Dlouhá J., Barton A., Janoušková S., Dlouhý J.	Social learning indicators in sustainability-oriented regional learning networks	2013	Journal of Cleaner Production
73	Dlouha, J; Machackova-Henderson, L; Dlouhy, J	Learning networks with involvement of higher education institutions	2013	Journal of Cleaner Production
74	Dumreicher H.	Chinese villages and their sustainable future: The European Union-China-Research Project "SUCCESS"	2008	Journal of Environmental Management
75	Duru M., Therond O., Fares M.	Designing agroecological transitions; A review	2015	Agronomy for Sustainable Development
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241	Sol J., Beers P.J., Wals A.E.J.	Social learning in regional innovation networks: Trust, commitment and reframing as emergent properties of interaction	2013	Journal of Cleaner Production
242	Soria-Lara J.A., Bertolini L., te Brömmelstroet M.	An experiential approach to improving the integration of knowledge during EIA in transport planning	2016	Environmental Impact Assessment Review
243	Steen-Adams M.M., Langston N., Adams M.D.O., Mladenoff D.J.	Historical framework to explain long-term coupled human and natural system feedbacks: Application to a multiple-ownership forest landscape in the Northern Great Lakes region, USA	2015	Ecology and Society
244	Stepanova, O	Conflict resolution in coastal resource management: Comparative analysis of case studies from four European countries	2015	Ocean & Coastal Management
245	Sterling S.	Learning for resilience, or the resilient learner? towards a necessary reconciliation in a paradigm of sustainable education	2010	Environmental Education Research

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246	Sternlieb F., Bixler R.P., Huber-Stearns H., Huayhuaca C.	A question of fit: Reflections on boundaries, organizations and social-ecological systems	2013	Journal of Environmental Management
247	Stone-Jovicich S.	Probing the interfaces between the social sciences and social-ecological resilience: Insights from integrative and hybrid perspectives in the social sciences	2015	Ecology and Society
248	Stringer L.C., Dougill A.J., Fraser E., Hubacek K., Prell C., Reed M.S.	Unpacking "participation" in the adaptive management of social-ecological systems: A critical review	2006	Ecology and Society
249	Tàbara J.D., Chabay I.	Coupling Human Information and Knowledge Systems with social-ecological systems change: Reframing research, education, and policy for sustainability	2013	Environmental Science and Policy
250	Tabara J.D., Pahl-Wostl C.	Sustainability learning in natural resource use and management	2007	Ecology and Society
251	Tidball K.G., Krasny M.E., Svendsen E., Campbell L., Helphand K.	Stewardship, learning, and memory in disaster resilience	2010	Environmental Education Research
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259	van Kerkhoff, LE; Lebel, L	Coproductive capacities: rethinking science-governance relations in a diverse world	2015	Ecology And Society
260	van Mierlo B., Leeuwis C., Smits R., Woolthuis R.K.	Learning towards system innovation: Evaluating a systemic instrument	2010	Technological Forecasting and Social Change
261	van Opstal M., Hugé J.	Knowledge for sustainable development: A worldviews perspective	2013	Environment, Development and Sustainability
262	Verduzco Chávez B., Bernal A.S.	Planning hydroelectric power plants with the public: A case of organizational and social learning in Mexico	2008	Impact Assessment and Project Appraisal
263	Vilsmaier U., Lang D.J.	Making a difference by marking the difference: Constituting in-between spaces for sustainability learning	2015	Current Opinion in Environmental Sustainability
264	Virji H., Padgham J., Seipt C.	Capacity building to support knowledge systems for resilient development-approaches, actions, and needs	2012	Current Opinion in Environmental Sustainability
265	Vogel C., Moser S.C., Kasperson R.E., Dabelko G.D.	Linking vulnerability, adaptation, and resilience science to practice: Pathways, players, and partnerships	2007	Global Environmental Change
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