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Knowledge management across the environment-policy interface in China: What knowledge is exchanged, why, and how is this undertaken?

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ABSTRACT

Global to local environmental policy-making is increasingly evidenced-based. Knowledge management (KM) is increasingly used by environmental scientists and policymakers, to deliver evidence-based policy and practice. There is thus an urgent need to identify whether and how knowledge is exchanged between knowledge producers and users in environmental science fields. Here we apply an assessment framework developed in social medicine to identify what forms of environmental knowledge are exchanged, and why and how they are exchanged. We focussed on China, as international research to better manage Chinese ecosystem services is rapidly-increasing, yet, how to best integrate this into political decision-making and the public realm remains a challenge. How KM is practiced in China is unknown. We addressed this through: 1) a systematic analysis of published KM research in China compared to global trends; 2) evaluating KM for environmental policy and management in China; 3) quantitative surveys of Chinese (n = 72) and British (n = 16) scientists researching Chinese environmental problems. The systematic literature review of two databases identified two key findings. One, of 291 papers that considered KM there were no papers in the environmental sector examining the science-policy-practice interface in China. Two, only 13 of 423 potentially relevant papers explicitly examined KM for environmental topics, notably for agriculture and information exchange (the 'What?'). Most papers reported a one-way interaction between scientists and users (the 'How?'), used to change practice (the 'Why?'). Our survey showed significantly-less awareness and use of two-way knowledge exchange (KE) methods by Chinese scientists. The paucity of documented KM research and limited evidence for two-way interaction show KE at the environmental science-policy-practice interface in China is limited. Promotion of KE practice may benefit environmental policy-making in China. We have also shown that conceptual frameworks for mapping and assessing KE practice from social medicine can be usefully adapted for examining environmental science – policy interfaces.

1. Introduction

Over the past three decades China has demonstrated outstanding economic growth (Wang, 2016; Wu, 2012). However this rapid economic growth in the world's most populous country (United Nations, 2017) is associated with environmental degradation including depletion of non-renewable resources, high pollutant emissions and destruction of ecosystems (Liu and Diamond, 2005; Wu, 2010; Zhang and Wen, 2008)(Liu and Diamond, 2005; Wu, 2010). In turn, serious environmental impacts on water, air and land in China (Hsu et al., 2016; Kan, 2014) have caused severe economic losses, social concerns and public health risks (Chen et al., 2013; Liu and Diamond, 2005; Wang, 2016). Due to the transboundary nature of air and water pollution and over-exploitation of natural resources for global markets, environmental issues in China have significant implications for the global environment, with direct or indirect effects (Chen et al., 2013).

With increasing public concerns and demand for environmental protection and better quality of life, Chinese policy makers need to ensure sustainability of economic growth (Wu, 2012). Increasing investment and reform of environmental protection policies have been implemented to better coordinate economic growth and environmental issues (Zhang and Wen, 2008) - for example, through promoting the 'Circular Economy' for a greener economy (Feng and Yan, 2007; Ghisellini et al., 2016). Furthermore, academic research into environmental management, human impact, and ecosystem services, on topics such as land use change (Liu et al., 2017; Long et al., 2006; Weng, 2002), soil erosion (Wang et al., 2007; Zhao et al., 2013) and air pollution (Chan and Yao, 2008; Huang et al., 2014), has been or is being

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undertaken to improve China's ecosystem services.

However, producing more scientific knowledge of environmental management does not necessarily transfer into better and actionable practice (Fazey et al., 2014) – it requires the 'users' to better access scientific knowledge that is tailored to their needs and ideally to co-design research so that the social and policy relevance of it improves. To date, exchange of knowledge has been defined in various ways and via multiple terms e.g., knowledge generation, knowledge transfer, coproduction and knowledge translation (Eivor et al., 2013; Fazey et al., 2013). Knowledge sharing (KS) and knowledge transfer (KT) are two of the most widely-applied in the literature with different implied meanings. KS is a knowledge sharing process, where both scientist and user knowledge is shared and valued, while during KT delivery, knowledge is regarded to be transferred and received in a linear, one-way direction from scientists to science users (Fazey et al., 2013). For example, in KT researchers may produce a technical report for science users with little or no coproduction with those who will use the report in everyday practice; this can also be termed the 'traditional' approach. Worldwide, knowledge exchange (KE) is used less-often than KS and KT. KE is considered similar to KS, but interest in this approach is growing. In KE practice, the exchange of knowledge occurs mutually between science 'producers' and 'users', and focuses on identifying and overcoming the obstacles to KE between them (Cvitanovic et al., 2015). This two-way exchange is thought to improve the impact of research on policy and practice, which can be conceptual (changing beliefs), symbolic (justifying existing policy positions) or instrumental (direct impacts on political decision making) (Rudd, 2011).

Thus, KT, KS and KE (hereafter together termed as knowledge management, KM) can be conceptualised as a spectrum from little or no engagement between scientists and science users in KT to a highly-engaged, coproduction of knowledge as KE. Many research projects involve elements of different KM, such as co-designing research questions or KE outputs from research projects, rather than adopting a KE approach throughout. These are considered hybrid approaches.

There is growing emphasis on identifying and developing effective KE practice in environmental management to better inform policy making and professional practice, leading to environmental and social-economic improvements (Cvitanovic et al., 2015; Fazey et al., 2013). Better communication, coproduction and two-way sharing between knowledge producers and users has been identified as being required (Bertuol-Garcia et al., 2018; Reed et al., 2014) to improve knowledge mobilisation at the environmental science-policy-practice interface. In response, there has been an increase in research on KE relevant to environmental policy and management in a wide range of fields (e.g. Raymond et al., 2010; Saarela and Söderman, 2015; Lucey et al., 2017; Reed et al., 2014). This has occurred mainly in the UK, USA, Canada and Australia.

With the increasing global influence of China, there is growing interest in research collaboration between China and other countries. To improve the usefulness of international research in China to, for example, inform evidence-based policy and practice, it is important to understand how the process of KE operates in China. However, we currently lack a basic understanding of *what* type of KE is delivered in China, and if so, *why* and *how* the knowledge is exchanged and *who* is involved in this process. We need to know this to help identify what practises are effective.

Using a systematic literature review of KE research in China, and a questionnaire survey of Chinese and British environmental scientists actively researching the environmental issues in China, we apply and extend a framework (developed for social medicine, Ward, 2017) to help identify what practises are effective:

1 *What* types of KM (including KT, KS and KE) have been conducted for all disciplines in China and how does this compare to global trends through time?
2 *Has* KM in China occurred across the environmental science-policy interface?
3 *Which* fields of environment science and management have published papers on their KM practice in China? *Why* is KM conducted and *how* is KM practiced?
4 *How* does the published environmental KM practice compare to the experiences of environmental scientists working in China? *What* types of KM are they practising and *how* have they used it for research?

Questions 2 and 3 are both designed to understand KM in China for environmental science and management involving science-policy interface, but from different angles. Question 2 is to investigate if any KM study with science-policy interface is relevant to the environmental science sector, while question 3 explores if the science-policy interface is involved in environmental KM studies.

In answering all above questions, we will apply a framework (extended from Ward, 2017) to assess KM practice and improve understanding of what forms of KM are researched, and why and how KM is used in the environmental science sector in China. This information can inform the design of future KE activity for environmental policy-making in China.

2. Research methods

Two complementary approaches were used to test the framework and answer the research questions: a systematic literature review and a quantitative survey of UK and Chinese scientists.

2.1. Systematic literature review (for Questions 1, 2 & 3)

2.1.1. Literature search

We used a systematic literature review process (Haddaway et al., 2015) to search, categorise and map the relevant global and China-focussed literature on KM. It allows mapping and quantifying of research findings and knowledge gaps (Pickering et al., 2015) and has been successfully used to critically review environmental management (e.g. Haddaway and Bilotta, 2016) and policy (e.g. Bilotta et al., 2014) topics.

The keywords used to search for literature were 'knowledge exchange (KE)', 'knowledge shar*' (KS) and 'knowledge transfer' (KT) (use frequency in literature shown in Supplementary Information (SI), Table S1). Although KS and KT are often considered as a one-way linear knowledge flow, there is inconsistency in what each refers to, so we searched for all three terms to provide a comprehensive understanding of knowledge delivery practice worldwide and in China. The initial literature search was systematically conducted using three widely-used academic databases: Web of Science™ (WoS, All database), Scopus and ProQuest. The searches of keywords were carried out in Topic in WoS or Article title, Abstract, Keywords in Scopus, and comprised all document types. No language restriction was applied. The search captured all articles published up to the end of 2017. The search for Question 1 compared outputs between WoS (All database) and Scopus, as ProQuest does not provide statistical analysis on the number of annual publications. These searches were refined to answer our specific questions (further details in SI 2).

Question 1 (primary question): The search was conducted for all disciplines by using the knowledge delivery-related terms. To compare China to worldwide trends, it was geographically refined to China after the search for global trends.

Questions 2 & 3 (secondary questions): Two searches were conducted based on the results of question 1. The relevant key screening criteria (Table S2) were performed in title to refine the results for 1) for science-policy interface and 2) environmental science and management. The captured publications were scanned carefully in title and abstract to filter out irrelevant articles according to our criteria (Fig. 1).

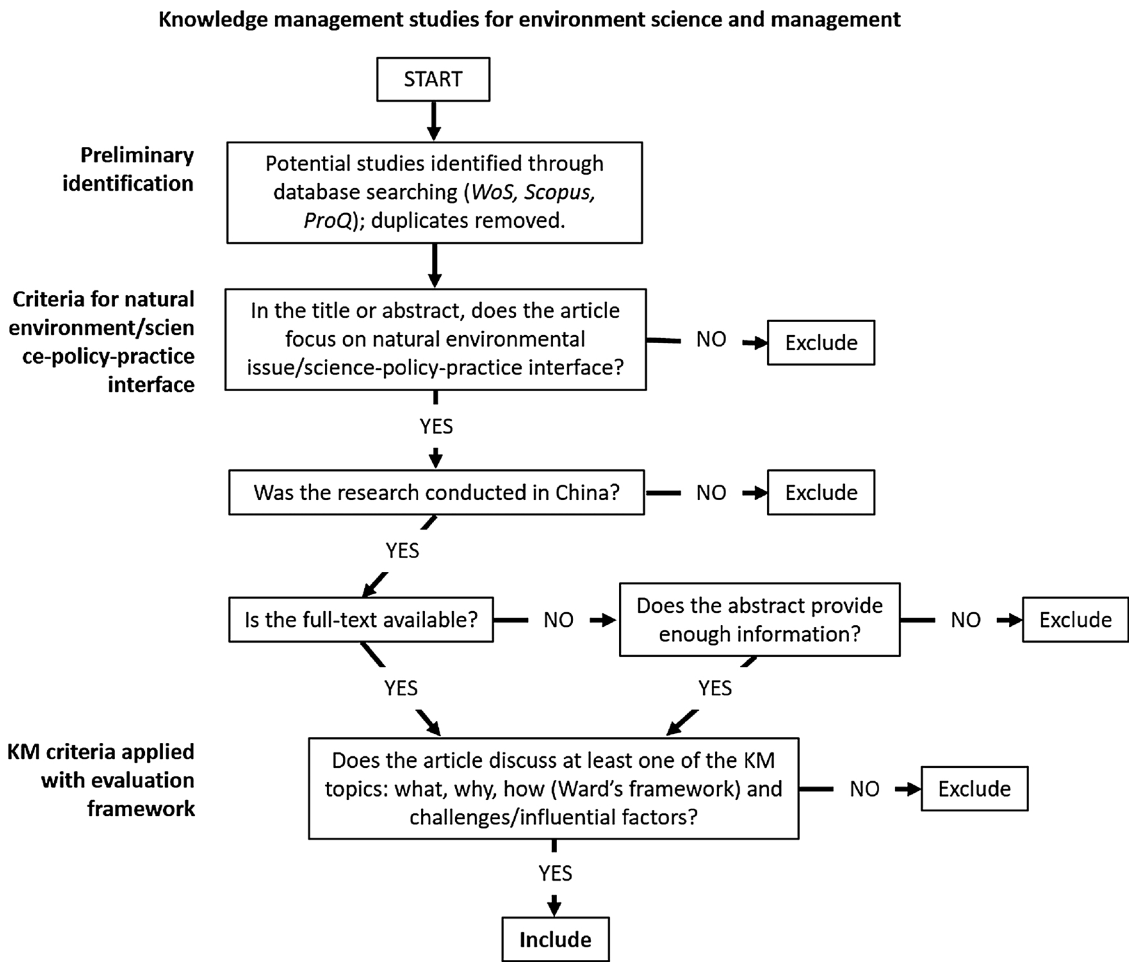

Fig. 1. Procedures for screening the identified articles for questions 2 & 3. Details about searching in electronic datasets are provided in Table S2.

2.1.2. Content analysis

The review results for questions 2 & 3 are presented in Figure S2. Content analysis involved coding all retained papers according to a series of criteria, drawing on the framework of Ward (2017) and by developing our own criteria for analysing *How* KE is carried out in terms of the nature and direction of knowledge flow and the types of tools and techniques used (Table 1). We also identified which environmental science and policy topics were discussed.

2.2. Survey method (for Questions 3 & 4)

It is possible that more KE is practised than reported via academic publications. To test this, we conducted 88 questionnaire surveys of British and Chinese environmental scientists studying the Chinese environment. The British scientists were chosen as the UK is more experienced in KE research than China and the comparison may provide helpful insights. Chinese (n = 27) and British (n = 16) scientists working across a joint international critical zone (CZ) project volunteered to complete the survey in project meetings or via email circulation. This allowed to compare KE awareness and practice between these two groups, and between the literature-generated KE analysis and local perspectives of scientists in China. We extended this voluntary survey to an additional 45 general Chinese environmental scientists (via surveys responses gathered at the 2017 International Geochemistry Conference in Guizhou, China) to examine if the response from Chinese scientists on the joint international project was representative of the

Table 1
Codes used for the papers identified for abstract/full-text analysis. Codes for ***WHAT*** and ***WHY*** are modified after Ward (2017).

Criteria	Code	Explanation for codes
WHAT?: type of knowledge	Tech	Technical knowledge consisting of practical experiences and skills
	Sci	Scientific knowledge from research findings
	Wi	Personal/public information, professional judgments, values, beliefs
WHY?: why undertake KM	Ch	To change practices or behaviours of local communities
	So	To develop solutions to practice-based problems
	Po	To develop new policies and/or recommendations
	Imp	To apply/implement well-defined policies or practices
HOW?: knowledge flow direction	One-way	The knowledge/information is passed in only one direction from knowledge sources to receivers (e.g. farmers), and feedback from the receivers does not happen
	Two-way	Where a mutual communication occurs, or knowledge/information is shared between the involved groups
HOW?: techniques/tools	ICT-based	Information & communication technologies (ICTs), e.g. programmed expert system, e-learning systems
	in-person	Involving face-to-face communication, e.g. interviews, participatory workshops

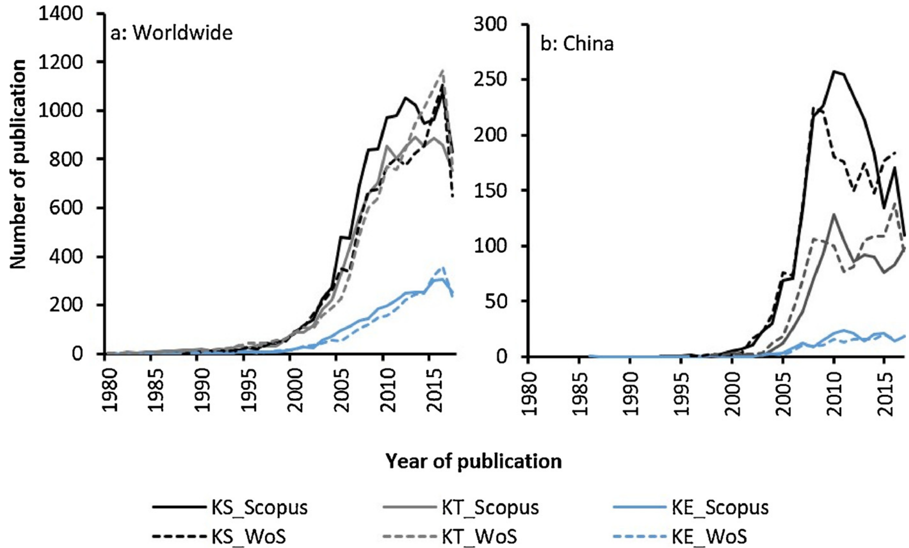

Fig. 2. Annual number of publication records related to KM research (including KE, KS and KT) for all disciplines from 1980 to 2017 in the world (a) and within China (b) from two databases: Scopus and Web of Science (WoS).

wider Chinese environmental science community. This understanding improved our ability to determine *what* types of KM are commonly conducted in China, and *how* KE is practiced by Chinese environmental scientists compared to UK scientists.

2.3. Statistical analysis for survey data

Tests for significance between the Chinese scientist groups, and between the Chinese and British CZ scientists were conducted using a test for two-sample proportions in Minitab® 17. When sample size was < 5, the results of Fisher's test was applied. The difference was considered significant at $p < 0.05$.

3. Results

3.1. Temporal and spatial variation of KM research for all disciplines

Prior to 1980, very little research on KM activities was published globally, while there has been a steady annual growth of KM research output since then (Fig. 2a). From 2000 onwards, in both the WoS and Scopus databases, the number of publications rapidly increased across all types of KM. Publication numbers were greatest for KS and least for KE, with KE representing 11% of the total number of papers in both databases. Publications reporting on KE research emerged since 2000 and have shown a more gradual global increase afterwards.

Published research on KM activities in China is similar to the global trend, with the fewest papers on KE (Fig. 2b), representing 6% (Scopus) and 5% (WoS) of the total KM publications in China. This was less than the global pattern. Furthermore, while KS- and KT-related annual outputs peaked around 2010, the annual number of KS-related publications has subsequently declined, and KT-related annual output has remained relatively stable.

Knowledge communication has attracted diverse research interest globally. A similar pattern was shown for both KS and KT (Fig. 3a, b), with the largest volume of published research from China, the USA and the UK. Chinese publications on KS represented the largest national contribution (2457) at 20% of the global KS database, while the USA contributed the highest number of KT publications (2072). For KE research (Fig. 3c), the UK had the largest number of publications (621), followed by the USA (493) and Canada (313). China ranked 5th with only 218 papers.

3.2. KM across the environmental science-policy interface in China

In the searches undertaken for question 2 (Figure S1a), twelve of 291 potentially relevant articles were identified as KM research across the Chinese science-policy-practice interface in China. However, none of these focused on environmental science and management. For question 3, after screening, only 13 studies discussing KM research for environment-related disciplines were identified for detailed manuscript analysis (Figure S1b).

3.2.1. What knowledge is exchanged, how and why?

Only a few environmental science topics have been explored. Agricultural knowledge and information (in 9 out of 13) was most often exchanged between different producer/user parties. This was followed by KM for water/land management (n = 2), climate change impacts on tourism (n = 1), and sustainable cities (n = 1). For these disciplines, various types of knowledge were shared (i.e. ***What*** knowledge), mainly comprising: 1) technical knowledge associated with practical experiences and skills ('*Tech*'); 2) scientific knowledge from research findings ('*Sci*'); 3) personal/public information, professional judgments, values, beliefs ('*Wi*'). The type of knowledge exchanged varied by topic: technical knowledge was most common for agriculture related papers, public opinion for climate change and tourism and scientific knowledge for water/land management papers.

The methods and approaches used for KM in the retained studies can be categorised into two types (Fig. 4, ***HOW***). The first category was online dissemination and collection of information/knowledge primarily or entirely based on information & communication technologies (ICTs, Ward, 2017). The second category was people-based involving face-to-face interactions, e.g. surveys and interviews, participatory workshops, and using information to make personal connections. A higher number of publications reported KM using ICT-based methods (n = 8), than by in-person connections that brokered relationships between groups (n = 5).

Four key reasons were identified for the papers discussing environmental science KE activity (Fig. 4, ***WHY***). The dominant intended purpose for the KE activity was to create solutions to local problems ('*So*', n = 10). For example, in one agricultural extension project, an ICT-based knowledge transfer model was analysed and developed to better promote local enhancement of the agricultural extension, and to enrich farmers' scientific knowledge (Feng et al., 2005). In some projects (n = 5), changing the practice and behaviour towards

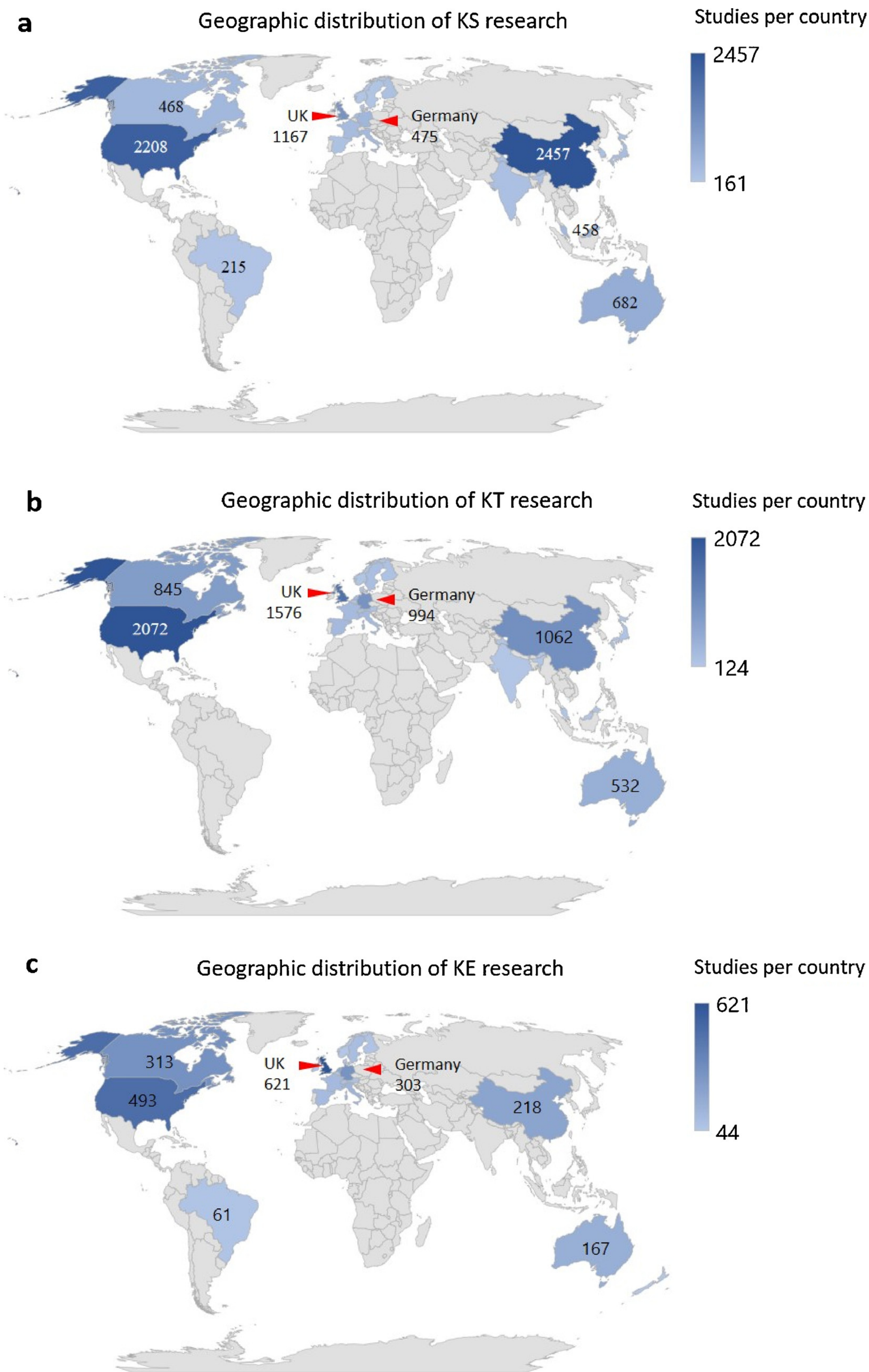

Fig. 3. Geographic distribution of three types of KM (a: KS; b: KT; c: KE) research globally. Total publications spanning full available timeframes were analysed. A similar pattern was found between the two databases, and Scopus data is shown as an example. The first top 20 countries are presented in the blue colour series (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

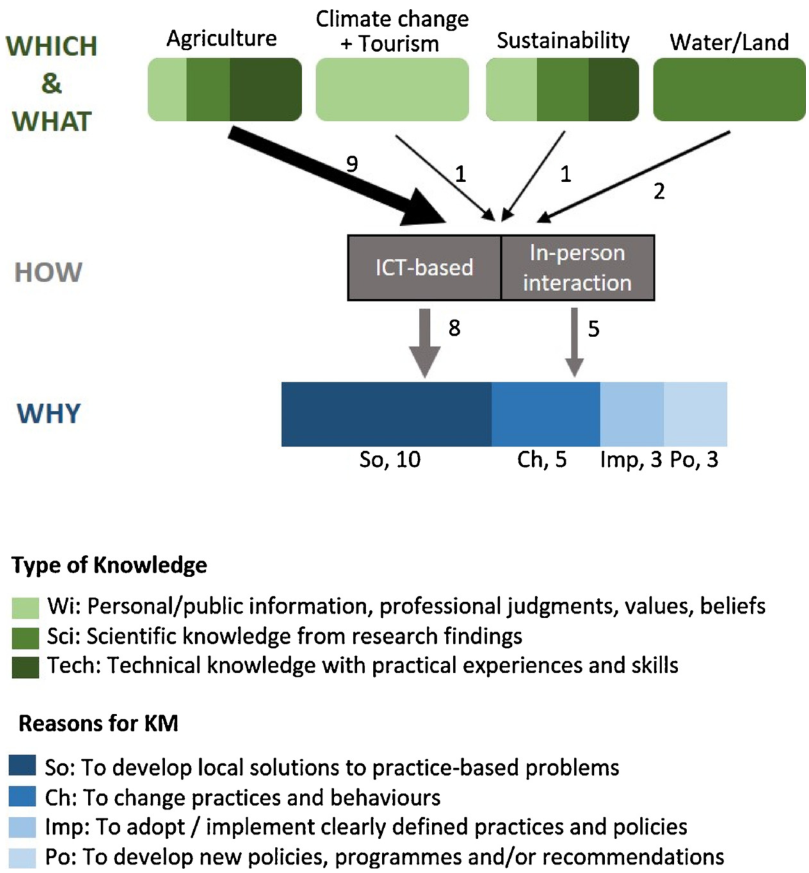

Fig. 4. What knowledge domain was exchanged between various parties, how it was exchanged and why. Data is synthesised from the retained full-text articles (n = 13) where the numbers refer to number of relevant publications and the area of each green/blue colour bar is positively related to the proportion of relevant categories (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

environmental management (‘*Ch*’) was the intended outcome from KM. Three studies reported KM activity linked to the development of new policies (‘*Po*’) for implementing relevant defined policies and practices (‘*Imp*’). For example, a water resource management project in Xinjiang Province used a transdisciplinary research approach to integrate scientific knowledge among researchers, and to inform government stakeholders for future evidence-based policy (Siew et al., 2014).

3.2.2. Knowledge flow: who is involved and to what extent was KE (two-way engagement) used?

We found that interactions within the wider public involving skilled practitioners (e.g. agriculture enterprises) and general public (e.g. residents) (n = 7), and between scientists and the wider public (n = 6), dominated (Fig. 5). In contrast, very few papers addressed science-policy interactions (n = 1) and policy-public interactions (n = 1). In general, the publications more frequently report on public interaction with scientists as part of the knowledge sharing and communication process, and less so with scientists exchanging or sharing knowledge with government officials.

There was a lack of consistency in terminology used to describe different types of KE. An accepted definition of KE is the two-way knowledge sharing between researchers and non-researchers (Fazey et al., 2013). However, in the 13 retained articles, KT and KS were more frequently applied as the terms for KE processes (both one/two-way) regardless of participating groups and knowledge flow direction (Fig. 5). This is similar to the preferences shown in the broader literature review results. The criteria we proposed (Table 1) allowed a better evaluation of knowledge sharing direction in spite of the inconsistent use of KM terms, and the results identified across the science-policy-practice interface, comparable numbers of unidirectional and mutual knowledge flow papers were evident (Fig. 5).

3.2.3. KE awareness and involvement of Chinese environmental scientists

The analysis of the survey responses from the Chinese and UK scientists found no significant difference between the two Chinese groups (27 CZ vs. 45 general environmental scientists) (Table 2), showing the Chinese CZ group was representative of the larger population of Chinese environmental scientists. Thus, only the responses from the Chinese CZ group were used to compare with the British CZ scientists' experience of KM, which enabled a comparison between scientists working collaboratively on research projects. In the questionnaire KT was used as an umbrella term instead of KM to describe general knowledge communication, involving three types of delivery: traditional (one-way delivery), hybrid (one-way but user-oriented delivery) and KE (multidirectional communication). For consistency we have used the term KM in the paper.

In the Chinese CZ group (n = 27), 52% identified they had experience of KM of any type (involving traditional, hybrid and KE) for communicating their science to wider users during their research career (Q1, Table 2). This was a lower proportion than the British CZ group (n = 16, 88%, $p < 0.05$). A significantly higher proportion of the UK group deployed ‘hybrid’ approaches for KM than the Chinese (mix of traditional unidirectional KT and mutual KE, $p < 0.05$; Q2, Table 2). No significant difference existed in other types. Making user-oriented KM tools (thus traditional or hybrid) was the most common approach used in UK (Q3, Table 2), while producing scientific report or academic papers only (thus little interaction) was the major way of making KT tools in China.

The types of KM outputs that had been produced by the two CZ groups (Q4, Table 2) were broadly similar. However, in UK, technical reports were more often produced as a KM output ($p < 0.05$). Moreover, a higher proportion of British scientists (50%) produced other kinds of KM outputs than the Chinese (4%, $p < 0.001$). This included producing video for decision-making tools, social media application, and participatory workshops to develop a project plan (not presented in

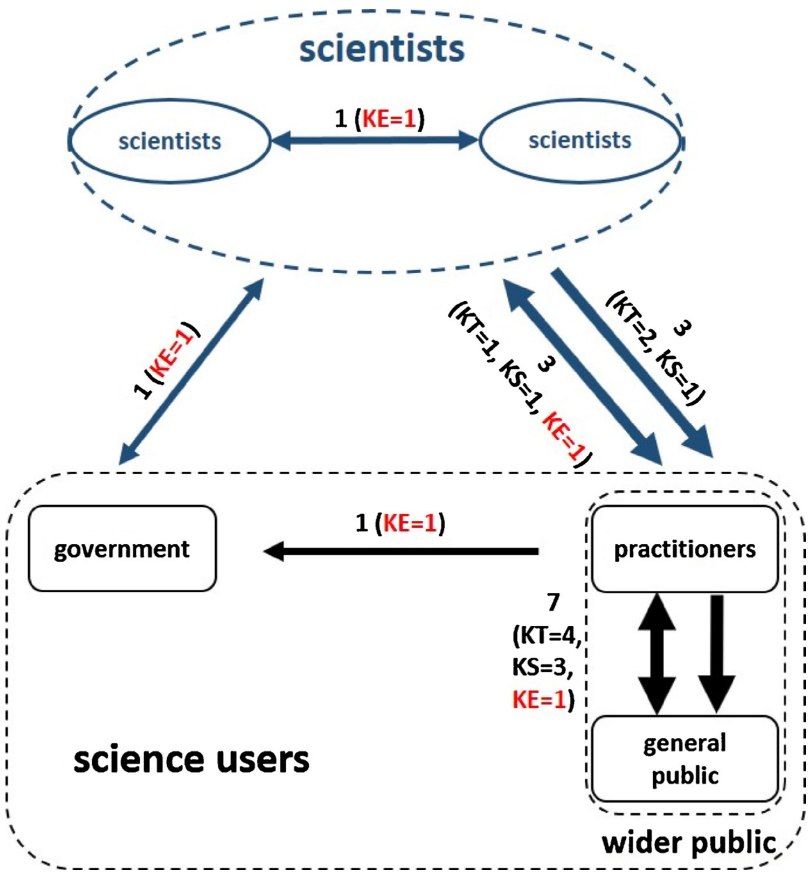

Fig. 5. The knowledge flow between science producers (scientists) and users (government and wider public) in the 13 reviewed studies. The blue-coloured circles and arrows represent the scientist-involved groups and interactions. The number represents the amount of relevant studies. The arrow size is positively-related to the number of the studies, and the direction shows the direction of knowledge flow (one-way or mutual). KT, KS and KE represent the terms used in the relevant studies, and some articles are not exclusive to one term. One study may have multiple KM interfaces (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

the table). Within the Chinese group, guidance for farmers was the most frequently-produced output, while technical reports were the major type of output for the UK group. Decision support tools and webinars were the least-favoured outputs by both groups.

The survey identified that participation in different mutual KE processes was similar for UK and Chinese scientists, with co-designing research questions with users being the most common method of KE engagement (Q5, Table 2). However, a significantly larger percentage of British than Chinese researchers used participatory workshops to involve users ($p < 0.05$).

4. Discussion

4.1. Fewer KM studies on environmental management topics in China

Between 2000–2010 there was a rapid worldwide development of research interests in KM, and recognition of the need to incorporate this into research. This pattern is similar to that shown in previous research (1970–2014, Cvitanovic et al., 2015), which reported on global published KM techniques from across the world via the Scopus database. Importantly, our results differentiated between different types of KM techniques and in doing so identified KE as a newer, much less-studied KM tool across all disciplines. Research interest in KE is clearly gaining global momentum, including in China.

However, assessing this spatial pattern needs careful interpretation. To date, an internationally consistent definition of two-way knowledge sharing has not been agreed (although KE typically involves two-way sharing). Our detailed review of knowledge flow direction in Chinese environmental science and policy literature (Fig. 5) showed that KT was still the dominant term used to describe two-way KM. This implies that what constitutes KE may be misunderstood or misreported by the research community, and it is crucial to assess the nature of the interaction (i.e. *how*, including one-way transfer or two-way sharing) when evaluating KM globally, and in China. Moving forward, KM terms need to be defined more clearly and applied more consistently; the criteria developed here to assess two-way knowledge flow will aid this process.

KT and KS represent the most common KM approaches in China but not in environmental science management. From our source filtering review, it appears that KM studies in China tended to focus on the importance of sharing knowledge for organization management, knowledge-based economy and healthcare policy development (e.g. Mabey et al., 2015; Yan et al., 2016; Zhang and Vogel, 2013) rather than the environment. That only 13 KM studies in China had been conducted for environmental research topics (and no papers examined the environmental science-policy-practice interface) suggests limited academic research interest in exploring and publishing about environmental science-related KM practice in China and recognition of KM as an independent research topic. This is not surprising as globally environmental management research has had limited engagement with KE (Fazey et al., 2013).

However there is evidence of KE-related activity outside of academic papers and conference proceedings via informal reports (e.g. *Success of the Science and Technology Program of Public Wellbeing in 2015* by the Institute of Geochemistry, CAS; only available in Chinese). The lack of published research attention to KM for environmental management, but more active KM practice was supported by our survey results, which showed that approximately half of the Chinese CZ scientists had KT experience in their research career. A research need therefore is to better understand what, why and how environmental science and management knowledge is exchanged between scientists and various users including policymakers, practitioners and various publics in China. There is also clear scope to help others understand the role of KE in improving evidence-based environmental policy for a range of pressing environment, resilience and sustainability topics.

In addition, a distinct lack of in-depth consideration of KE is evident in the Chinese environmental research publications, assessed by our KE

Table 2
The survey results from Chinese and British CZ scientists, and the significance analysis for each of the KM options (traditional, hybrid and mutual). The numbers outside the brackets represent the number of respondents, and inside represent the percentage. A two-sample proportion test was conducted for each option, with $p < 0.05$ interpreted as significant difference (marked in italics and coloured in red). In the original survey, we used knowledge transfer, as the umbrella term instead of knowledge management; this is equivalent to knowledge management (KM) in the table below.

Options	Chinese CZ (n = 27*)	British CZ (n = 16)	Estimate for difference	p value
Q1. Have you ever done (any type of) knowledge transfer (i.e. knowledge management) to users during your research career?				
Yes	*14 (52 %)*	*14 (88 %)*	*−0.36*	*< 0.05*
No	*13 (48 %)*	*2 (13 %)*	*0.36*	*< 0.05*
Q2*. Which types of knowledge transfer (i.e. knowledge management) have you done?				
No experience	*12 (46 %)*	*2 (13 %)*	*0.34*	*< 0.05*
Traditional (unidirectional)	9 (35 %)	9 (56 %)	−0.22	n.s.
KE	5 (19 %)	7 (44 %)	−0.25	n.s.
Hybrid	*4 (15 %)*	*9 (56 %)*	*−0.41*	*< 0.05*
Q3. Did you make these (KT, i.e. KM) tools WITH end users (e.g. KE) or did you make them FOR end users (e.g. traditional or hybrid KT), or not at all?				
No experience	*12 (44 %)*	*2 (13 %)*	*0.32*	*< 0.05*
Scientific report/academic papers (no interaction)	9 (33 %)	5 (31 %)	0.02	n.s.
For end users (traditional or hybrid KT)	*5 (19 %)*	*11 (69 %)*	*−0.50*	*< 0.01*
With end users (KE)	4 (15 %)	5 (31 %)	−0.16	n.s.
Q4*. What types of knowledge transfer (any type of knowledge transfer, i.e. knowledge management) outputs have you been involved in making?				
No experience	*12 (46 %)*	*2 (13 %)*	*0.34*	*< 0.05*
Farmer's guidance	7 (27 %)	4 (25 %)	0.02	n.s.
Technical report	*6 (23 %)*	*9 (56 %)*	*−0.33*	*< 0.05*
Policy briefing	5 (19 %)	6 (38 %)	−0.18	n.s.
Training workshops	5 (19 %)	6 (38 %)	−0.18	n.s.
Best practice guidance	3 (12 %)	5 (31 %)	−0.20	n.s.
Decision support tools	2 (8 %)	3 (19 %)	−0.11	n.s.
Webinars	1 (4 %)	2 (13 %)	−0.09	n.s.
Other	*1 (4 %)*	*8 (50 %)*	*−0.46*	*< 0.001*
Q5*. What types of knowledge exchange processes have you used to help deliver knowledge transfer (i.e. knowledge management) to date?				
No experience	*11 (42 %)*	*3 (19 %)*	*0.24*	*n.s.*
Co-designed research questions	*7 (27 %)*	*9 (56 %)*	*−0.29*	*n.s.*
Co-produced KE outputs with end users	*6 (23 %)*	*6 (38 %)*	*−0.14*	*n.s.*
Secondment in an end user organisation	*4 (15 %)*	*2 (13 %)*	*0.03*	*n.s.*
Participatory workshops to get end users involved in making KE outputs	*3 (12 %)*	*9 (56 %)*	*−0.45*	*< 0.01*
Other	*0 (0)*	*3 (19 %)*	*−0.19*	*< 0.05*

* The responded number of people was 26; n.s. not significant.

framework. Four key research areas (*KE engagement*, *process*, *evaluation* and *objectives*) were identified related to the KE cycle (Fazey et al., 2013), among which '*exploring KE process*' was the most common question of KM research (Fazey et al., 2013). This is further supported by our research as all 13 Chinese environmental KM studies analysed were associated with identifying better KM tools and techniques (Fig. 4). Mainly ICT-based approaches were applied for KM in these published studies (*how* in the framework) which aligns well with a broader Chinese trend of using ICT for information exchange (Li and Reimers, 2015; Zhang et al., 2016). However, there has been longstanding awareness about the positive benefits of using both social and technical approaches for effective KM (Bhatt, 2001; Pan and Scarbrough, 1998) – which was lacking in the papers reviewed here. Furthermore, assessments of the quality of KE (e.g. *engagement* and *evaluation*) were not discussed in the identified publications. This, and the lack of Chinese scientist experience with KE, illustrates that to ensure policy is designed effectively crucial social aspects of KE processes and the specialist skills required by KE practitioners (e.g. Bednarek et al., 2018) could be greatly developed in Chinese KE research and practice.

4.2. Practical experience of brokering across the science-policy-practice interface

The analysis of knowledge flow revealed limited knowledge communication (both unidirectional and multidirectional – *how*) between environmental scientists and users (e.g. government and the wider public) in China (Fig. 5) and no project scale KM for environmental management. However, the scientist survey provided a slightly different insight.

Overall, the Chinese group had statistically larger percentage of scientists showing no experience applying knowledge delivery in their research (46–48%) and thus producing any type of KM tools and outputs (44–48%) than the British (13%) (Table 2). For those Chinese with KM experience, a higher proportion of them used traditional unidirectional sharing approaches (35%), while a lower proportion used KE (19%) for knowledge communication (Table 2, Q2). This suggests that more communication and interaction between environmental scientists and science users occurs locally in China than indicated in the literature. Co-designing projects was the most popular type of KE process for both scientist groups (although 29% lower in the Chinese). However, staff exchange was underutilised as a KE mechanism by both the Chinese and British research communities, with only 15% and 13% of the surveyed scientists having carried out a secondment in a user organisation. Increasing stakeholder involvement and facilitating dialogue has been suggested to greatly help shape research activities and improve knowledge co-production and thus KE efficiency and effectiveness (Phillipson et al., 2012). Continuous communication throughout the project lifetime also helps to improve knowledge uptake by the participants and mutual benefits can be generated through stakeholder participation in research advisory groups, or staff exchanges (Sitas et al., 2016). A much larger proportion of the British scientists had chosen to use participatory workshops to involve science users in the process of KE output production compared to the Chinese scientists. The lack of mutual communication of knowledge and experience between knowledge producers and users in China may have hindered the achievement of environmental management, sustainability, poverty reduction or resilience goals.

Generally, approaches to KM were more varied among the UK scientists surveyed, with the use of traditional, hybrid and KE sharing practices recognised as common mechanisms of KM. 'Traditional' (i.e. one-way with no direct interaction such as producing academic papers) approaches were most frequently used by the Chinese group (35%). Reasons for this are unclear, although one explanation may be that the belief that knowledge can be passed from producers to users in an inactive form (Fazey et al., 2014) is operating among the Chinese research community, with less consideration given to how to maximise the effectiveness of knowledge uptake by users (Reed et al., 2014), and minimal recognition of the added-value learning from local users can have (e.g. local knowledge, Ward, 2017). This may explain the lack of environment-related KM publications retained after systematic literature review. The Chinese research community may benefit from increasing the amount of interactive and participatory activities such as workshops with their users, and in advance with their policy-makers, to help develop and create long-term, sustained relationships, and in doing so, lead to improved evidence-based policy and decision making.

5. Conclusion

Five key conclusions can be drawn from this research. First, the amount of published work on KM in China differs from the experiences of environmental scientists surveyed, suggesting there is a sizable gap between research on KM approaches and the practice of KM by environmental scientists in China. Second, our adaptation of Ward (2017) KE framework for discriminating and categorising KE components (*What, How* and *Why*) has supported an assessment of knowledge flow direction, allowing KE approaches to be more clearly identified. This approach can therefore be widely applied when conducting future research on environmental science and policy KE. Third, to be effective, the global KM research community would greatly benefit from the use of clearer, more consistently applied KM terminology that takes better account of the directions of knowledge flow.

Fourth, KE practice varies between UK and Chinese environmental scientists where fewer Chinese scientists practiced KE and they used more traditional KT techniques compared to greater use of KE methods (e.g. user-involved activities) by the British environmental scientists surveyed. The more limited recognition of KE in China as an independent research subject, while increasingly recognised in many other countries as essential to facilitating social, economic and environmental research impact, presents an opportunity for collaboration with fellow scientists who can offer training and help implement more effective KE in China. This, alongside, increased support for KE research by domestic research foundations, will help develop KE research and practice in China. For example, creating research initiatives to increase the focus on and design processes for KE (e.g. via KE research fellows) could be an important conduit to provide the underpinning environmental science evidence to inform policy and practice.

Lastly, research on the environmental science-policy-practice interface in China is also notably absent and so there is a need for more effective KE to explore this interface in the Chinese environmental science and policy context. This is needed to help deliver improved evidence-based policy and practice, by bringing together different forms of knowledge, including environmental science to address pressing environmental policy issues in China and other rapidly developing regions.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.envsci.2018.09.021.

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