ENVIRONMENTAL SCIENCE & POLICY 40 (2014) 16–25

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/envsci

Roles of scientists as policy advisers on complex issues: A literature review

Pita Spruijt [a,b,*], *Anne B. Knol* [b], *Eleftheria Vasileiadou* [c], *Jeroen Devilee* [b], *Erik Lebret* [a,b], *Arthur C. Petersen* [c,d]

[a] *Institute for Risk Assessment Sciences, Utrecht University, Utrecht, The Netherlands*
[b] *Centre for Sustainability, Environment and Health, National Institute for Public Health and the Environment (RIVM), Bilthoven, The Netherlands*
[c] *Institute for Environmental Studies, VU University Amsterdam, Amsterdam, The Netherlands*
[d] *PBL Netherlands Environmental Assessment Agency, Bilthoven, The Netherlands*

ARTICLE INFO

Keywords:
Roles of scientists
Policy advice
Complex issues
Scientific experts
Scientometrics

ABSTRACT

Background and Aims: Policymakers frequently encounter complex issues, and the role of scientists as policy advisers on these issues is not always clearly defined. We present an overview of the interdisciplinary literature on the roles of scientific experts when advising policymakers on complex issues, and in particular on the factors that influence these roles.
Methods: A structured literature search was combined with literature found in reference lists of peer reviewed papers (the snowball method). In total, 267 publications were analyzed using scientometrics analyses (discipline clustering analysis and co-citation analysis) followed by a qualitative analysis and interpretation.
Results: The scientometrics analysis shows an amalgam of disciplines that publish on our research topic. Five clusters of authors were identified based on similarities in the references used: post-normal science, science and technology studies, science policy studies, politics of expertise and risk governance. The content of the clusters demonstrates that authors in different clusters agree that the role of experts is influenced by the type of problem (simple or complex) and by other parties (the public and stakeholders). However, opinions vary on the extent to which roles can vary and the necessity to explicate different viewpoints.
Discussion and conclusions: Publications on scientific experts who provide policy advice affirm that such experts should and do hold different roles, depending on the type of problem and factors such as values held by the expert and the type of knowledge. We conclude that research on expert roles has remained mostly theoretical. Existing theories about science systems can be used to study real policy advice processes. Most theories are well elaborated, but empirical proof for the described changes, roles and processes is limited.

* *Corresponding author at*: Centre for Sustainability, Environment and Health, National Institute for Public Health and the Environment (RIVM), Bilthoven, The Netherlands. Tel.: +31 302747018; fax: +31 2744451.
E-mail address: pita.spruijt@rivm.nl (P. Spruijt).

http://dx.doi.org/10.1016/j.envsci.2014.03.002

1. Introduction

Policymakers are frequently confronted with complex issues. Highly industrialized countries are almost inevitably faced with new technologies that entail high degrees of uncertainty (Beck, 1992). In addition, some of the more mainstream environmental issues, such as air pollution, are still not fully resolved, and economic and environmental concerns are often considered contradictory. Scientists are regularly asked to advise on such complex issues. However, their role as policy advisers is not always clearly defined. This ambiguity is particularly true for contested issues, such as synthetic biology, antimicrobial resistance and nanotechnology. Because these issues are so new, it is impossible to present long-term research results that give a clear and unequivocal overview of the potential risks involved. Uncertainties inherent in such issues permit differences in the appraisal of risks. When experts differ in their interpretation of the uncertainty and consequently give different advice, these differences can affect the decisions of policymakers. An example is the topic of electromagnetic fields: uncertainty about the effect of electromagnetic fields has led to a situation in which some countries have adopted a precautionary approach and others have emphasized the absence of proof of adverse health effects and therefore have not implemented any policy interventions (Kheifets et al., 2001; Van Dijk et al., 2011).

In recent years, scholars have addressed the ways in which experts assess complex issues in a policy-relevant manner (Jasanoff and Wynne, 1998; McNie, 2007; Hessels and Van Lente, 2008). Approaches to policy advice and matching research and policy questions are addressed by a diverse set of theoretical concepts, such as wicked problems (Churchman, 1967; Rittel and Webber, 1973), ill-structured problems (Dunn, 1988; Simon, 1977), messy problems (Ackoff, 1974), unstructured problems (Hisschemöller and Hoppe, 2001), intractable issues (Eeten, 2001; Hisschemöller and Hoppe, 2001), systemic risks (OECD, 2003; Briggs, 2008) and untamed problems (WRR, 2006). Despite the diversity in terminology, a common characteristic of these concepts is that they refer to uncertain and potentially risky issues that merit a transdisciplinary approach, which indicates that these risky issues are embedded in wider environmental, social, economic and political systems (Beck, 1992; Sarewitz, 2004; Renn and Graham, 2005; Klinke and Renn, 2006; Briggs, 2008; Van Asselt, 2010; Van Asselt and Renn, 2011). In this paper, we refer to these types of issues as complex issues.

In 1945, Merton wrote about the role of scientific experts in policymaking. He particularly addressed the lack of empirical data on the actual roles of experts with respect to public policy (Merton, 1945). Furthermore, Merton suggested that common frustrations in the interaction between scientists and policymakers are related to (1) conflicts of values and (2) the different ways in which bureaucratic and academic organizations function (time horizons, communication styles, etc.). Then, as now, scholars note the peculiarity of studying the role of their own profession (Merton, 1945; Jasanoff, 2013).

Theories focusing specifically on scientists as policy advisers provide insights into common struggles in practice. For example, many policymakers seek certainties and solutions, whereas scientists typically offer probabilities, uncertainty and multiple scenarios. It is a complicated task to reconcile these different perspectives. To improve decision-making processes, it is necessary to bridge the resulting "science–policy gap" (Bradshaw and Borchers, 2000; Choi et al., 2009). Intermediaries between scientists and policymakers can help bridge this gap (Gieryn, 1983; Choi et al., 2005; Hoppe, 2009). However, others express the view that there is no gap but rather a continuous interaction between science and policy (Wesselink et al., 2013). In any case, the interaction between scientists and policymakers is intricate when the specific issue is surrounded by scientific uncertainties. To understand and discuss these interactions, several researchers have presented typologies and theories about the different roles of scientists as policy advisers on complex issues and the factors that influence such roles (Funtowicz and Ravetz, 1990; Hisschemöller and Hoppe, 1995; Weiss, 2003; Pielke, 2007). Although these studies address the possibility of different roles among experts, empirical support is scarce (Hoppe, 2009; Spruijt et al., 2013; Turnhout et al., 2013). Moreover, a comprehensive overview of the published literature on expert roles and their determinants has not been conducted. Such a review is essential as a first step toward using the knowledge about expert roles in practice and improving the interaction between scientists and policymakers. Therefore, we present a systematic literature review conducted to answer the following question: What are the factors that influence the way scientific experts advise policymakers on complex issues?

2. Methods

We conducted the literature search using two digital search engines: Scopus and Web of Knowledge. (Window 1) outlines the literature selection and key words used. Two researchers simultaneously performed the manual refinement. Differences in the assessment by the two researchers were discussed and led in most cases to dismissal of the publications. The three main reasons for dismissal were a language other than English, irrelevant content (e.g., similar keywords but different content, such as computer sciences) and the absence of an abstract (time constraints did not permit us to read full papers without first being able to filter on the basis of an abstract). We reviewed work published between 2003 and 2012 to obtain a workable number of papers. We assumed that influential ideas from older literature were sufficiently incorporated in the literature published during this ten-year period.

Because some major work appeared to not be published in peer-reviewed journals, we expanded our structured search using the snowball method. This approach required us to read and follow the reference lists of the publications identified in the structured search. After excluding duplicates, we found a total of 297 articles, books and book chapters. Fig. 1 shows a flow diagram of the literature selection process.

The final selection of publications was then subjected to a qualitative review. In parallel, a scientometrics analysis was performed to analyze the distribution of the publications

```
TITLE(expert OR expertise OR (stakeholder W/3 (dialogue OR role OR perspective OR conflict*)))

AND
 ((((TITLE-ABS-KEY(expert W/3 (role OR factor OR scien* OR excellen* OR professional* OR perspective OR competenc* OR dialogue* OR epistemic*)))

OR (TITLE-ABS-KEY(expertise W/3 (role OR factor OR scien* OR excellen* OR professional* OR perspective OR competence OR dialogue* OR epistemic*)))))

OR ((TITLE-ABS-KEY(stakeholder W/3 (role OR factor OR scien* OR excellen* OR professional* OR perspective OR competence OR dialogue OR conflict* OR epistemic))))))

OR

((TITLE((scien* W/5 poli*) OR (scien* W/5 expert*))) AND (TITLE-ABS-KEY(boundary OR epistemic OR advocacy OR value OR perspectiv* OR worldview OR interaction* OR interface OR policy-advice OR policy-mak* OR decision-mak*)))

AND ( LIMIT-TO(SUBJAREA,"SOCI" ) OR LIMIT-TO(SUBJAREA,"ENVI" ) OR LIMIT-TO(SUBJAREA,"PSYC" ) OR LIMIT-TO(SUBJAREA,"ARTS" ) OR LIMIT-TO(SUBJAREA,"SOCI" ) OR LIMIT-TO(SUBJAREA,"ENVI" ) OR LIMIT-TO(SUBJAREA,"PSYC" ) OR LIMIT-TO(SUBJAREA,"ARTS") OR LIMIT-TO(SUBJAREA,"DECI" ) OR LIMIT-TO(SUBJAREA,"MULT" ) OR LIMIT-TO(SUBJAREA,"MULT" ) ) AND PUBYEAR > 2003
```

Window 1 – Structured search strategy.

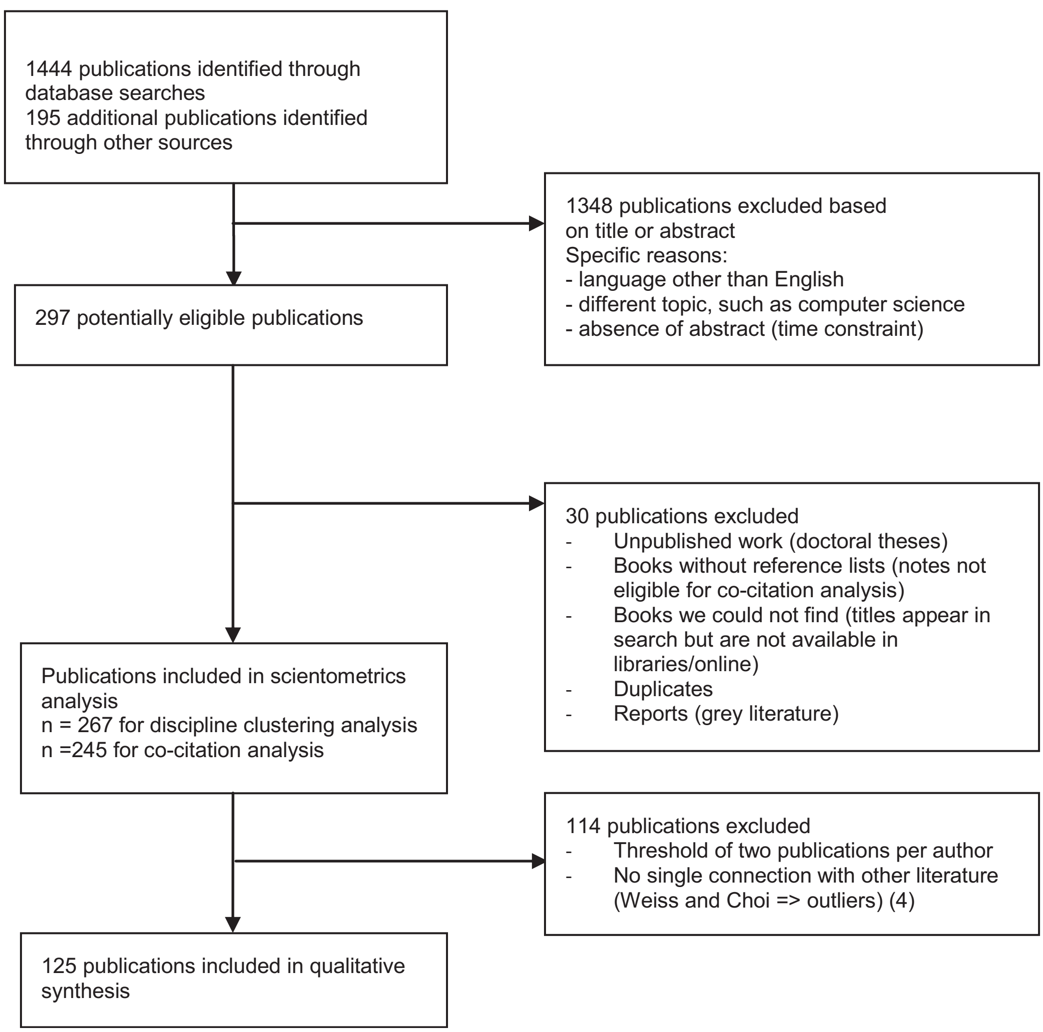

Fig. 1 – Flow diagram outlining the literature selection process.

among different disciplines. We used Leydesdorff et al. (2013) science overlay map in combination with the Pajek program for this analysis (Nooy et al., 2005; Rafols et al., 2010) (see the supplementary material for the results of the discipline analysis).

We conducted a co-citation analysis to structure the literature based on the references used. In a co-citation analysis, a set of publications (two or more) is bibliographically coupled when these publications have a citation of one or more papers in common (e.g., A and B both cite C).

Furthermore, co-citation analysis is based on identifying pairs of cited references; a pair of publications is strongly correlated when they are co-cited in more than one paper (Garfield, 2001). The web-based program VOSviewer (VOS = Visualization of Similarities) was used to conduct the co-citation analysis. The identified clusters then formed the framework for the qualitative review.

For the discipline analysis, we used all of the selected publications. For the co-citation analysis, we were not able to use all the publications because some had references that we could not import into the analysis program VOSviewer, such as publications in which notes were used instead of reference lists of peer-reviewed journal articles. In total, we excluded 22 publications from the co-citation analysis. The remaining 245 publications were analyzed in VOSviewer. Authors with two or more publications were included in the analysis, regardless of the position of the author in the author list (first, second, last), resulting in the selection of work by 55 different authors. After reading the papers, we excluded another six publications, presented by VOSviewer in two separate clusters, because they did not focus on the role of scientific experts as policy advisers. In total, 125 publications were included in the qualitative review. The full list of publications is included as supplementary material.

3. Results

We found 12 distinct clusters based on the co-citation analysis of the reference lists of 53 authors. Using the 12 clusters identified in the co-citation analysis as a starting point, and after a subsequent grouping based on content, we distinguished five clusters (see Fig. 2). These clusters were assigned the following overarching labels: Post-normal science, Science and technology studies, Science policy studies, Politics of expertise, and Risk governance. These names were chosen because they represent, as closely as possible, the author groups' self-proclaimed research approaches (not disciplines). The labels all address the interdisciplinarity of the discussed work, which matches our attempt to address literature published in journals from different disciplines and from authors with different scientific backgrounds. The labels are meant to facilitate easier reading of the paper but are not meant as strict and uncontestable denominators of all papers represented in the cluster. Overall, the literature addresses the question of what factors influence the ways in which scientific experts advise policymakers on complex issues. The various clusters mostly answer either the question of "what factors influence" or the question of "what factors should influence"

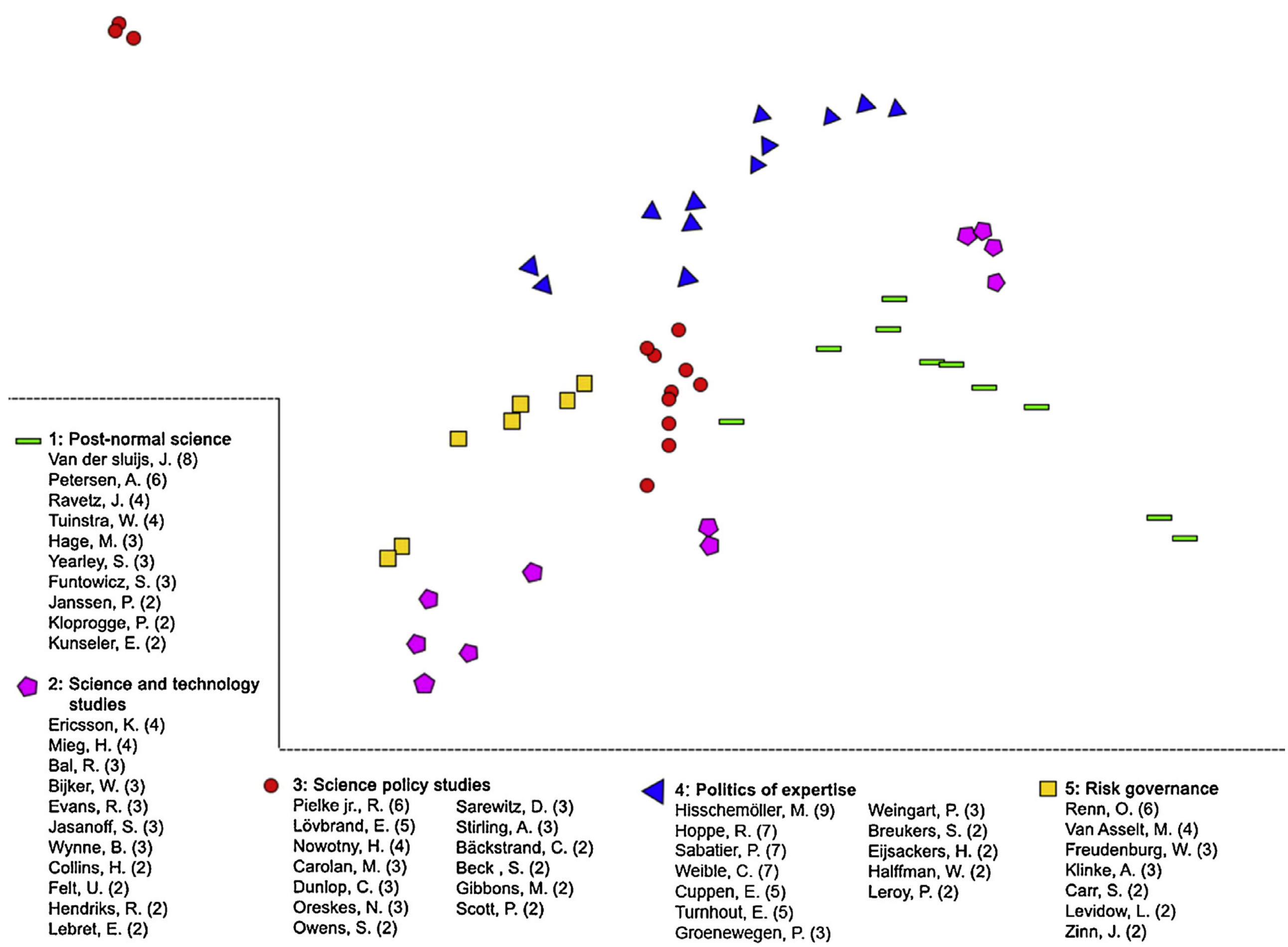

Fig. 2 – Co-citation analysis of cited references.

the role of a scientific expert when advising policymakers. The first question leads to descriptive/empirical research; the second question leads to more theoretical/normative work. In the following sections, we discuss which question is addressed by each cluster.

3.1. Cluster 1: post-normal science (ten authors, 22 publications)

Post-normal science is addressed in a line of research that first started in the 1980s, indicating that, especially for environmental risk-related policies, different types of questions and research are needed than for ''traditional'' problems because uncertainty and complexity are inevitable (Funtowicz and Ravetz, 1992, 1993). The problem-solving strategy called ''post-normal science'' is appropriate when decision stakes and system uncertainties are high, in contrast to normal science, which is effective when decision stakes and uncertainties are low. Earlier studies explained the theoretical basis of post-normal science, whereas later studies described empirical analyses in contexts such as air quality (Tuinstra, 2007) (references to studies within each cluster can be found in the supplementary material).

Three key elements in the post-normal science paradigm are the following (Petersen et al., 2011): (1) the management of uncertainty; (2) the management of a plurality of perspectives within and outside of science; and (3) the internal and external extension of the peer community. These elements play out as follows. First, post-normal science acknowledges that uncertainty is more than a technical number or methodological issue. Ambiguous knowledge assumptions and ignorance give rise to epistemological uncertainty. Second, solving complex issues requires scientific teamwork within an interdisciplinary group and joint efforts by specialists from the scientific community and from business, politics, and society. Third, an extended peer community includes representatives from social, political, and economic domains that openly discuss various dimensions of risks and their implications for all stakeholders.

Post-normal science authors propose that the role of scientific experts in the policy process should depend on the type of problem (normal or post-normal). This role is also dependent on individual characteristics, as experts cope with uncertainty in different ways by adapting to it to various degrees (Van der Sluijs, 2005). When problems are complex and uncertain, more parties – such as the public – should be involved in the decision-making process (Yearley 2006). In addition, uncertainty and complexity should be explicitly addressed to allow for critical reflection on the advice process (transparency) (Petersen et al., 2011).

3.2. Cluster 2: science and technology studies (11 authors, 22 publications)

Science and technology studies (STS) is an interdisciplinary field that studies how social, political and cultural dimensions affect scientific research and technological innovation and how these, in turn, affect society, politics and culture. The publications in this cluster present mainly general theories as well as publications on public health issues in The Netherlands. Central to the work of all authors in this cluster is the question of what constitutes the legitimacy of (scientific) expertise, especially when experts are confronted with complex and contested policy issues. These authors question established delineations of both experts and expertise.

According to the authors in this group, scientific experts should position themselves in accordance with what are called ''technologies of humility''. This expression means that when coping with complex issues, the possibility of unforeseen consequences as well as the normative assumptions inherent in the technical information should be made explicit (Jasanoff, 2003). Thus, experts and expert committees should not attempt to offer unequivocal advice on the best policy option but rather present various policy options and describe the limits of science (Bijker et al., 2009). To increase the acceptance of policy measures among different groups, it is beneficial to acknowledge the necessity of plural viewpoints. STS authors suggest discourse analysis as a way to detect and describe multiple viewpoints. The basic assumption of discourse analysis is that language profoundly shapes experts' views of the world and reality rather than being merely a neutral medium mirroring it (Hajer, 2006).

Collins and Evans make a distinction between interactive expertise and contributory expertise. Interactive expertise is the formal and informal (written) language of a specialty, whereas contributory expertise is the (un)consciously internalized practical skills of a specialty. Expertise is based on experience, and people are experts in a particular field (Mieg, 2006, 2009). The skills of experts are not necessarily transferable to another field (Ericsson and Ward, 2007). Ericsson posits specifically that people become experts after ten years of deliberate practice (Ericsson and Lehmann, 1996).

In summary, the STS scholars teach us that experts should be aware that no type of knowledge is purely objective. When providing policy advice, scientific experts should be aware of and transparent about the context and the social construction of knowledge as well as their own normative assumptions to offer a balanced picture of scientific knowledge to decision makers. This openness implies that science should embrace public participation when confronted with complex issues.

3.3. Cluster 3: science policy studies (13 authors, 33 publications)

The studies in this cluster are both empirical, e.g., case studies, and theoretical, e.g., outlines of factors that should influence the interactions between scientists and policymakers (just as in cluster 2). More specifically, publications in this cluster address empirical questions, such as what we see and what we can do in practice. Other publications examine expert roles from a more theoretical and almost idealistic point of view, as with the central concept Mode 2. Nowotny, Gibbons and Scott introduced Mode 2 science in *The New Production of Knowledge* (Gibbons et al., 1994). They argue that a new form of knowledge production emerged in the mid-20th century and that the nature of the research process is being transformed toward knowledge production in a more democratic way. They labeled this new form Mode 2. Science policy studies is the cluster with the most authors and is centrally located on the co-citation output map. However, as Fig. 2 shows, the Mode 2 authors occupy an outlying position because work on Mode 2 was categorized within management studies, and most of the references related to work on Mode 2 were categorized within the management and organization sciences disciplines.

A recurring topic in the Science policy cluster is criticism of the linear model of science: the authors propose and discuss ways to democratize science (Bäckstrand, 2003; Pielke, 2004; Lövbrand and Öberg, 2005; Carolan, 2006; Lövbrand, 2007; Carolan, 2008). Democratizing science should lead to socially robust knowledge (Nowotny, 2003, 2007). Experts should interact with stakeholders and the public at large to ensure robust decision-making processes (Burgess et al., 2007; Stirling, 2008; Lövbrand et al., 2011). Methods that can facilitate decision processes for contested issues include, for example, stakeholder dialogs, epistemic communities and deliberative mapping (Burgess et al., 2007; Stirling et al., 2007; Dunlop, 2009).

Furthermore, these authors argue that the role of scientific experts is influenced by their values and viewpoints when uncertainty is inherently present. Because science is not able to answer all questions concerning complex and uncertain risks, experts should be transparent about their values and viewpoints (Sarewitz, 2004; Burgess et al., 2007; Carolan, 2008). Being transparent about the indicators that influence the advising process is part of professional humility (Beck, 2011), which is an appropriate attitude when complexity and uncertainty are inevitable (cf. Jasanoff, 2003, STS cluster).

In short, science cannot solve all complex issues. To adequately address uncertainty and obtain socially robust knowledge, scientific experts should be transparent about their viewpoints, interact with stakeholders and the public and work with an attitude of professional humility. Several science policy authors have presented and tested methods that facilitate complex decision-making processes.

3.4. *Cluster 4: politics of expertise (12 authors, 32 publications)*

Politics of expertise authors address the power relationships in the science–policy interface, with the central question being how to effectively organize interaction at this interface (Hisschemöller and Hoppe, 2001; Turnhout and Leroy, 2004; Hage and Leroy, 2007; Hage et al., 2010). These authors are classified into three groups.

The first group of authors focuses on the advocacy coalition framework (ACF) as a tool to explain how coalitions of experts form and how such coalitions can lead to policy change (Weible et al., 2009). These authors seek to answer the question of what factors influence the role of scientific experts as follows: around any policy subject, there are multiple coalitions of experts with potentially conflicting beliefs. Within and between coalitions, there are different normative beliefs, which in the ACF are referred to as the three-tiered hierarchical structure of (1) deep core beliefs, (2) policy core beliefs and (3) secondary beliefs. Experts who hold similar policy core beliefs form a coalition (cf. Sabatier and Jenkins-Smith, 1993). The influence of a coalition on the policy process and the ability of people to learn from each other and/or incorporate new scientific knowledge into their belief system are central to the framework. In this process, deep core beliefs and policy core beliefs are the most resistant to change. Empirical applications of ACF show that in concrete policy processes, the role of science is influenced by the policy context (Weible, 2008; Weible and Sabatier, 2009; Weible et al., 2010), that coalition membership is relatively stable over time (Weible et al., 2009) and that experts' policy core beliefs are important in explaining their policy preferences and thus are strongly linked to the position of an expert or coalition (Weible et al., 2004; Weible, 2007; Weible and Moore, 2010).

The authors in the second group share the view that scientific knowledge should be socially robust in times of the "scientification of society" and the "politicization of science" (Weingart, 1997, 1999; Souren et al., 2007). These authors attempt to answer the question regarding what factors influence the role of scientific experts as follows: experts differ in the ways in which they organize their role in the science–policy interface. What happens in the science–policy interface is the translation of science into policy, which is a political process in which the different roles of experts and the different regulatory patterns of organizations can be observed (Halffman, 2005; Halffman and Hoppe, 2005; Souren et al., 2007; Hoppe, 2009). These differences are subject to change; Van Eijndhoven and Groenewegen (1991) found that experts are flexible in their argumentation and able to change viewpoints. Hoppe notes that the differences in the views of boundary workers have hardly been studied (Hoppe, 2008). Boundary workers are employees that are involved in facilitating collaboration between scientists and non-scientists (Guston, 2001).

The authors in the third group answer the question of what factors should influence the role of scientific experts as follows: scientific experts who provide policy advice on complex issues should participate in stakeholder dialogs. The purpose of a dialog is to articulate competing perspectives so that stakeholders can learn from each other. Additionally, dialogs can facilitate constructive conflict, which means that even when stakeholders do not agree, they can develop an understanding of each other's perspectives (Cuppen, 2012). Furthermore, the role of an expert in a dialog is dependent on the context (Turnhout et al., 2007, 2008).

In conclusion, scientific experts can hold different perspectives when advising on complex issues. Therefore, stakeholder dialogs can be used to facilitate learning and mutual understanding and prevent unnecessary conflict. The beliefs of scientific experts and those of the organizations (or systems) in which they work influence, to a greater or lesser extent, their policy preferences and most likely their policy advice on complex issues. However, the roles of scientists are subject to change.

3.5. *Cluster 5: risk governance (seven authors, 16 publications)*

Risk governance refers to the actions, processes and institutions by which authority is exercised and decisions are made regarding ways to advance societal benefits resulting from change while minimizing the negative consequences of risks (Renn and Graham, 2005). Risk governance scholars draw attention to the fact that not all risks are simple and not all risks can be calculated as a function of probability and effect

(Zinn, 2004; Taylor-Gooby and Zinn, 2006). Many risks that require societal choices and decisions are complex, uncertain and/or ambiguous. One group of authors in this cluster represents the theoretical basis of risk governance; the other group represents empirical research on European risk management.

These authors answer the question of what factors should influence the role of scientific experts as follows: scientific experts should characterize environmental health issues as simple, complex, uncertain or ambiguous. Depending on the type of problem, they can provide advice themselves (on simple issues) or involve other stakeholders (on ambiguous issues). The latter is a means of trying to reconcile the various frameworks from which different stakeholders may operate when interpreting a risk (Renn and Graham, 2005). Risk governance scholars also present the regulative option of the precautionary principle in case there is uncertainty in the knowledge base. Levidow and Carr show that in the European expert debate on the issue of genetically modified (GM) crops, experts found themselves in a value conflict that was resolved by using the precautionary principle (Levidow et al., 2005). The precautionary principle is a way to resolve – temporarily – what is called the uncertainty paradox: it is recognized that science cannot provide decisive evidence on every risk, while at the same time, policymakers increasingly call on science to provide conclusive evidence (Van Asselt and Vos, 2006).

Overall, according to these authors, it is important to recognize various types of complex issues. Depending on the type of issue, scientific experts should involve other parties to a greater or lesser extent. As long as values are in dispute and uncertainty remains, the precautionary principle is a way to accommodate uncertainty and differing perspectives.

4. Discussion and conclusions

The objective of this study was to review publications on the subject of (factors that influence) the roles of scientists when advising policymakers on complex issues. More knowledge on this subject may ultimately lead to an improved uptake of scientific information in policy processes and possibly to more effective and accepted policy measures. We identified five clusters of authors, based on similarities in references that were identified using scientometrics and on similarities identified in a subsequent content analysis. The clusters were labeled Post-normal science, Science and technology studies, Science policy studies, Politics of expertise and Risk governance.

The role of scientific experts when advising policymakers on complex issues is, according to the literature, influenced by the type of issue (simple or complex), the type of knowledge an expert has, the core values of an expert, the organization in which an expert works, the changing beliefs of experts and the context (e.g., the position of scientific knowledge and scientists within societies is changing, and calls for public participation and transparency are stronger, especially for complex issues surrounded by uncertainty). Suggestions have been made to improve the ways in which experts (should) deal with advising on complex issues, including using other types of knowledge, such as non-academic lay knowledge; adopting a professional attitude of humility; encouraging public participation (i.e., stakeholder dialogs); considering the option of precautionary measures; and explicating different points of view within the expert community.

In general, the authors in the different clusters agree on the changing positions of science and scientific experts in society and the focus on socially robust knowledge and on the democratization of knowledge. This focus leads to calls for transparency and public participation. However, opinions vary on what most strongly influences experts' advice when confronted with complex issues. Suggestions include expertise (years of professional education and practical training), context, beliefs, other stakeholders, the public and the type of issue (simple or complex). Thus, publications on scientific experts who provide policy advice affirm that these experts (should) hold different roles depending on the type of problem and specific background factors.

Tables 1 and 2 present a schematic overview of the factors and suggestions discussed with respect to each cluster. Some of these factors and suggestions are discussed in most clusters, and others are discussed in only one cluster. Thus, the clusters are not mutually exclusive in content. If a factor is mentioned in the majority of papers in a cluster, this is indicated by a tick in table. This tick does not automatically indicate that all authors assigned to that cluster explicitly discuss that factor or necessarily think that it is a key notion. Tables 1 and 2 present the best, yet subjective, effort of the authors to summarize the vast and diverging work published within all clusters. We realize that, in doing so, we will undoubtedly have cut some corners and lost some of the richness and subtleties presented in the primary publications.

Our search strategy covered a ten-year period and excluded a substantial number of publications, mainly as a consequence of the used search terms targeting our primary research question and also as a result of technical restrictions. Therefore, we do not claim that the selected publications

Table 1 – Factors that influence the role of an expert.

Factors that influence the role of an expert	Cluster number					Improvable
	1	2	3	4	5	
Type of issue (level of uncertainty/complexity)	x	x		x	x	–
Type of knowledge of the expert	x	x	x			+
Core values of the expert				x		–
Organization in which the expert works				x		+
Context (position of science in society)		x	x	x		–
Changing beliefs of experts			x	x		+

Table 2 – Suggestions to improve ways in which experts (should) advise on complex issues.

Suggestions to improve ways in which experts (should) advise on complex issues	Cluster number				
	1	2	3	4	5
Transparency in methods, assumptions, etc.	x	x	x		
Professional attitude of humility		x	x		
Public participation, democratizing science (i.e., stakeholder dialogs)	x	x	x	x	x
Precautionary principle					x
Explicating different points of view within the expert community	x	x	x		

reflect all available publications from all disciplines. We do feel that the identified clusters cover all primary viewpoints that exist about the subject. However, a longer search period, less restricting search criteria and more resources to include papers without abstracts would have produced a larger literature base. Adopting such strategies might have yielded somewhat different cluster patterns.

Even though our results focus on complex environmental issues, we do not believe that they are limited to those issues. We can imagine that for any given issue that is surrounded by uncertainty and complexity and about which scientific experts are asked to advise policymakers, e.g. economic and social issues, the role of scientific experts depends on several key factors. These factors include the complexity of the issue at stake, the type of knowledge and values that the experts have and contextual factors, such as the types of organizations in which the experts are employed or the broader societal context.

Despite Merton's recognition in 1945 that little empirical research had been conducted on the actual roles of experts, the content of the clusters demonstrates that research on expert roles has remained mostly theoretical. Although case studies on expert roles have been conducted, empirical verification of theories is often lacking, partly because most theoretical publications describe a hypothetical normative situation that ''should be'' achieved rather than the current situation that can be investigated empirically. This gap becomes especially clear when examining the scientific work on the apparent changes in scientific knowledge production and use (post-normal science, Mode 2 science, etc.). Most work in this area has emphasized describing ideas and trends and conducting analyses on higher aggregate levels. This work examines the differences not between the viewpoints or roles of individual experts but rather between scientific committees and policy sectors, among others (Hoppe, 2009). Existing theories about science systems can be used to study real policy-advising processes. Given that most theories are well elaborated and empirical proof for the described changes, roles or processes is limited, empirically testing these theories is a logical next step.

Acknowledgements

The authors would like to thank Jeanine Ridder for her assistance in the structured search strategy and Maximilian Nugroho for his technical support in the scientometrics analysis. Furthermore, we thank the participants of the VU University's Science and Values in Environmental Governance research group meetings for their useful comments on an earlier version of this paper. The work was financed through the Strategic Research Program RIVM.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.envsci.2014.03.002.

References

Ackoff, R.L., 1974. Redesigning the Future: a system approach to societal problems. John Wiley & Sons, NY.

Bäckstrand, K., 2003. Civic science for sustainability: reframing the role of experts, policy-makers and citizens in environmental governance. Global Environ. Politics 3 (4) 24–40.

Beck, U., 1992. Risk Society: Towards a New Modernity. Sage, London, UK.

Beck, S., 2011. Moving beyond the linear model of expertise? IPCC and the test of adaptation. Reg. Environ. Change 11 (2) 297–306.

Bijker, W.E., Bal, R., Hendriks, R., 2009. The Paradox of Scientific Authority: The Role of Scientific Advice in Democracies. The MIT Press, Cambridge, MA.

Bradshaw, G.A., Borchers, J.G., 2000. Uncertainty as information: narrowing the science-policy gap. Conserv. Ecol. 4 (1) 7.

Briggs, D.J., 2008. A framework for integrated environmental health impact assessment of systemic risks. Environ. Health 7 (1) 61.

Burgess, J., Stirling, A., Clark, J., Davies, G., Eames, M., Staley, K., Williamson, S., 2007. Deliberative mapping: a novel analytic-deliberative methodology to support contested science-policy decisions. Public Underst. Sci. 16 (3) 299–322.

Carolan, M.S., 2006. Science, expertise, and the democratization of the decision-making process. Soc. Nat. Res. 19 (7) 661–668.

Carolan, M.S., 2008. The politics in environmental science: the Endangered Species Act and the Preble's mouse controversy. Environ. Polit. 17 (3) 449–465.

Choi, B.C.K., Pang, T., Lin, V., Puska, P., Sherman, G., Goddard, M., Ackland, M.J., Sainsbury, P., Stachenko, S., Morrison, H., Clottey, C., 2005. Can scientists and policy makers work together? J. Epidemiol. Community Health (1979–) 59 (8) 632–637.

Choi, B.C.K., Gupta, A., Ward, B., 2009. Good thinking: six ways to bridge the gap between scientists and policy makers. J. Epidemiol. Community Health 63 (3) 179–180.

Churchman, C.W., 1967. Guest editorial: wicked problems. Manage. Sci. 14 (4) B141–B142.

Cuppen, E., 2012. Diversity and constructive conflict in stakeholder dialogue: considerations for design and methods. Policy Sci. 45 (1) 23–46.

Dunn, W.N., 1988. Methods of the second type: Coping with the wilderness of conventional policy analysis. Review Policy Res. 7 (4) 720–737.

Dunlop, C.A., 2009. Policy transfer as learning – capturing variation in what decision-makers learn from epistemic communities. Policy Stud. 30 (3) 289–311.

Eeten, M.J.G.v., 2001. Recasting intractable policy issues: the wider implications of the Netherlands civil aviation controversy. J. Policy Anal. Manage. 20 (3) 391–414.

Ericsson, K.A., Lehmann, A.C., 1996. Expert and exceptional performance: evidence and maximal adaptation to task constraints. Annu. Rev. Psychol. 47 (1) 273.

Ericsson, K.A., Ward, P., 2007. Capturing the naturally occurring superior performance of experts in the laboratory: toward a science of expert and exceptional performance. Curr. Dir. Psychol. Sci. 16 (6) 346–350.

Funtowicz, S.O., Ravetz, J.R., 1990. Uncertainty and Quality in Science for Policy. Kluwer Academic Publishers, Dordrecht.

Funtowicz, S.O., Ravetz, J.R., 1992. Risk management as a post-normal science. Risk Anal. 12 (1) 95–97.

Funtowicz, S.O., Ravetz, J.R., 1993. Science for the post-normal age. Futures 25 (7) 735–755.

Garfield, E., 2001. From Bibliographic Coupling to Co-citation Analysis via Algorithmic Historio-bibliography. Drexel University, Philadelphia.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., Trow, M., 1994. The New Production of Knowledge; The Dynamics of Science and Research in Contemporary Societies. Sage Publications Ltd., Stockholm, Sweden.

Gieryn, T.F., 1983. Boundary-work and the demarcation of science from non-science: strains and interests in professional ideologies of scientists. Am. Sociol. Rev. 48 (6) 781–795.

Guston, D.H., 2001. Boundary organisations in environmental policy and science: an introduction. Sci. Technol. Human Values 26 (4 (Special Issue: Boundary)) 399–408.

Hage, M., Leroy, P., 2007. Leidraad Stakeholderparticipatie voor het Milieu-en Natuurplanbureau: Hoofddocument. PBL, Bilthoven23.

Hage, M., Leroy, P., Petersen, A.C., 2010. Stakeholder participation in environmental knowledge production. Futures 42, 254–264.

Hajer, M.A., 2006. Doing discourse analysis: coalitions, practices, meaning. In: Brink, M.v.d., Metze, T. (Eds.), Words Matter in Policy and Planning; Discourse Theory and Method in the Social Sciences, vol. 344. Netherlands Geographical Studies., Utrecht, pp. 65–74.

Halffman, W., 2005. Science–policy boundaries: national styles? Sci. Public Policy 32 (6) 457–467.

Halffman, W., Hoppe, R., 2005. Science/policy boundaries: a changing division of labour in Dutch expert policy advice. In: Maasen, S., Weingart, P. (Eds.), Democratization of Expertise? Exploring Novel Forms of Scientific Advice in Political Decision Making. Kluwer, Dordrecht.

Hessels, L.K., Van Lente, H., 2008. Re-thinking new knowledge production: a literature review and a research agenda. Res. Policy 37, 740–760.

Hisschemöller, M., Hoppe, R., 1995. Coping with intractable controversies: the case for problem structuring in policy design and analysis. Knowl. Technol. Policy 8 (4) 40–60.

Hisschemöller, M., Hoppe, R., 2001. Coping with intractable controversies: the case for problem structuring in policy design and analysis. In: Hisschemöller, M., Hoppe, R., Dunn, W.N., Ravetz, J.R. (Eds.), Knowledge, Power, and Participation in Environmental Policy Analysis. Policy Studies Review Annual, vol. 12. Transaction Publishers, New Brunswick, New Jersey.

Hoppe, R., 2008. Scientific advice and public policy: expert advisers' and policymakers' discourses on boundary work. Poiesis Prax 6, 235–263.

Hoppe, R., 2009. Scientific advice and public policy: expert advisers' and policymakers' discourses on boundary work. Poiesis Prax 6 (3/4) 235–263.

Jasanoff, S., 2003. Technologies of humility: citizen participation in governing science. Minerva 41, 233–244.

Jasanoff, S., 2013. The science of science advice. In: Doubleday, R., Wilsdon, J. (Eds.), Future Directions for Scientific Advice in Whitehall. University of Cambridge.

Jasanoff, S., Wynne, B., 1998. Science and decision making. In: Rayner, S., Malone, E.L. (Eds.), Human Choice & Climate Change, vol. 1. Battelle Press, Columbus, Ohio, pp. 1–87.

Kheifets, L.I., Hester, G.L., Banerjee, G.L., 2001. The precautionary principle and EMF: implementation and evaluation. J. Risk Res. 4 (2) 113–125.

Klinke, A., Renn, O., 2006. Systemic risks as challenge for policy making in risk governance. Forum: Qual. Social Res. 7 (1) Art. 33.

Levidow, L., Carr, S., Wield, D., 2005. European Union regulation of agri-biotechnology: precautionary links between science, expertise and policy. Sci. Public Policy 32 (4) 261–276.

Leydesdorff, L., Carley, S., Rafols, I., 2013. Global maps of science based on the new Web-of-Science categories. Scientometrics 94 (2) 589–593.

Lövbrand, E., 2007. Pure science or policy involvement? Ambiguous boundary-work for Swedish carbon cycle science. Environ. Sci. Policy 10 (1) 39–47.

Lövbrand, E., Öberg, G., 2005. Comment on "How science makes environmental controversies worse" by Daniel Sarewitz, Environ. Sci. Policy, 7, 385–403 and "When Scientists politicise science: making sense of the controversy over The Skeptical Environmentalist" by Roger A. Pielke Jr., Environ. Sci. Policy, 7, 405–417. Environ. Sci. Policy 8, 195–197.

Lövbrand, E., Pielke, R., Beck, S., 2011. A democracy paradox in studies of science and technology. Sci. Technol. Hum. Values 36 (4) 474–496.

McNie, E.C., 2007. Reconciling the supply of scientific information with user demands: an analysis of the problem and review of the literature. Environ. Sci. Policy 10 (1) 17–38.

Merton, R.K., 1945. Role of the intellectual in public bureaucracy. Social Forces 23 (4) 405–415.

Mieg, H.A., 2006. System experts and decision making experts in transdisciplinary projects. Int. J. Sustain. High. Educ. 7 (3) 341–351.

Mieg, H.A., 2009. Two factors of expertise? Excellence and professionalism of environmental experts. High Abil. Stud. 20 (1) 91–115.

Nooy, W.d., Mrvar, A., Batagel, V., 2005. Exploratory Social Network Analysis with Pajek. .

Nowotny, H., 2003. Democratising expertise and socially robust knowledge. Sci. Public Policy 30 (3) 151–156.

Nowotny, H., 2007. How many policy rooms are there? Evidence-based and other kinds of science policies. Sci. Technol. Hum. Values 32 (4) 479–490.

OECD, 2003. Emerging Systemic Risks. Final Report to the OECD Futures Project. OECD, Paris, France.

Petersen, A.C., Cath, A., Hage, M., Kunseler, E., Van der Sluijs, J.P., 2011. Post-normal science in practice at the Netherlands environmental assessment agency. Sci. Technol. Hum. Values 36 (3) 362–388.

Pielke Jr., R.A., 2004. When scientists politicize science: making sense of controversy over The Skeptical Environmentalist. Environ. Sci. Policy 7 (5) 405–417.

Pielke Jr., R.A., 2007. The Honest Broker: Making Sense of Science in Policy and Politics. Cambridge University Press, Cambridge, UK.

Rafols, I., Porter, A.L., Leydesdorff, L., 2010. Science overlay maps: a new tool for research policy and library management. J. Am. Soc. Inform. Sci. Technol. 61 (9) 1871–1887.
Renn, O., Graham, P., 2005. White Paper on Risk Governance: Towards an Integrative Approach. IRGC, Geneva, Switzerland.
Rittel, H.W.J., Webber, M.M., 1973. Dilemmas in a general theory of planning. Policy Sci. 4, 155–169.
Sabatier, P.A., Jenkins-Smith, H.C., 1993. Policy Change and Learning: An Advocacy Coalition Approach. Westview Press, Boulder, Colorado.
Sarewitz, D., 2004. How science makes environmental controversies worse. Environ. Sci. Policy 7, 385–403.
Simon, H.A., 1977. The structure of ill-structured problems. Models of discovery. Springer, 304–325.
Souren, A.F.M.M., Poppen, R.S., Groenewegen, P., van Straalen, N.M., 2007. Knowledge production and the science-policy relation in Dutch soil policy: results from a survey on perceived roles of organisations. Environ. Sci. Policy 10 (7-8) 697–708.
Spruijt, P., Knol, A.B., Torenvlied, R., Lebret, E., 2013. Different roles and viewpoints of scientific experts in advising on environmental health risks. Risk Anal. 33 (10) 1844–1857.
Stirling, A., 2008. Science, precaution, and the politics of technological risk – converging implications in evolutionary and social scientific perspectives. In: Tucker, W.T., Ferson, S., Finkel, A.M. (Eds.), Strategies for Risk Communication: Evolution, Evidence, Experience, 1128. Wiley-Blackwell, Malden, pp. 95–110.
Stirling, A., Lobstein, T., Millstone, E., 2007. Methodology for obtaining stakeholder assessments of obesity policy options in the PorGrow project. Obes. Rev. 8 (Suppl. 2) 17–27.
Taylor-Gooby, P., Zinn, J.O., 2006. Current directions in risk research: new developments in psychology and sociology. Soc. Risk Anal. 26 (2) 397–411.
Tuinstra, W., 2007. Preparing for the European Thematic Strategy on air pollution: at the interface between science and policy. Environ. Sci. Policy 10 (5) 434–444.
Turnhout, E., Leroy, P., 2004. Participeren in onzekerheid. Literatuuronderzoek naar het inzetten van participatie in wetenschappelijke beleidsadvisering. RIVM, Bilthoven.
Turnhout, E., Hisschemöller, M., Eijsackers, H., 2007. Ecological indicators: between the two fires of science and policy. Ecol. Indic. 7 (2) 215–228.
Turnhout, E., Hisschemöller, M., Eijsackers, H., 2008. Science in Wadden Sea policy: from accommodation to advocacy. Environ. Sci. Policy 11 (3) 227–239.
Turnhout, E., Stuiver, M., Klostermann, J., Harms, B., Leeuwis, C., 2013. New roles of science in society: different repertoires of knowledge brokering. Sci. Public Policy 40 (3) 354–365.
Van Asselt, M.B.A., 2010. Nieuwe risico's in het vizier [New risks in the picture]. The Hague, Raad voor Ruimtelijk, Milieu-en Natuuronderzoek (RMNO) .
Van Asselt, M.B.A., Renn, O., 2011. Risk governance. J. Risk Res. 14 (4) 431–449.
Van Asselt, M.B.A., Vos, E., 2006. The precautionary principle and the uncertainty paradox. J. Risk Res. 9 (4) 313–336.
Van der Sluijs, J., 2005. Uncertainty as a monster in the science-policy interface: four coping strategies. Water Sci. Technol. 52 (6) 87–92.
Van Dijk, H.F.G., Van Rongen, E., Eggermont, G., Lebret, E., Bijker, W.E., Timmermans, D.R.M., 2011. The role of scientific advisory bodies in precaution-based risk governance illustrated with the issue of uncertain health effects of electromagnetic fields. J. Risk Res. 14 (4) 451–456.
Van Eijndhoven, J., Groenewegen, P., 1991. The construction of expert advice on health risks. Social Stud. Sci. 21 (2) 257–278.
Weible, C.M., 2007. Stakeholder perceptions of scientists: Lake Tahoe environmental policy from 1984 to 2001. Environ. Manage. 40 (6) 853–865.
Weible, C.M., 2008. Expert-based information and policy subsystems: a review and synthesis. Policy Stud. J. 36 (4) 615–635.
Weible, C.M., Moore, R.H., 2010. Analytics and beliefs: competing explanations for defining problems and choosing allies and opponents in collaborative environmental management. Public Admin. Rev. 70 (5) 756–766.
Weible, C.M., Sabatier, P.A., 2009. Coalitions, science, and belief change: comparing adversarial and collaborative policy subsystems. Policy Stud. J. 37 (2) 195–212.
Weible, C.M., Sabatier, P.A., Lubell, M., 2004. A comparison of a collaborative and top-down approach to the use of science in policy: establishing marine protected areas in California. J. Policy Stud. 32 (2) 187–208.
Weible, C.M., Sabatier, P.A., McQueen, K., 2009. Themes and variations: taking stock of the advocacy coalition framework. Policy Stud. J. 37 (1) 121–140.
Weible, C.M., Pattison, A., Sabatier, P.A., 2010. Harnessing expert-based information for learning and the sustainable management of complex socio-ecological systems. Environ. Sci. Policy 13 (6) 522–534.
Weingart, P., 1997. From finalization to mode 2: old wine in new bottles? Social Sci. Inf. 36 (4) 591–613.
Weingart, P., 1999. Scientific expertise and political accountability: paradoxes of science in politics. Science Public Policy 26 (3) 151–161.
Weiss, C., 2003. Scientific uncertainty and science-based precaution. Int. Environ. Agree.: Polit. Law Econ. 3 (2) 137–166.
Wesselink, A., Buchanan, K.S., Georgiadou, Y., Turnhout, E., 2013. Technical knowledge, discursive spaces and politics at the science–policy interface. Environ. Sci. Policy 30 (0) 1–9.
WRR, 2006. Lerende overheid: een pleidooi voor probleemgerichte politiek. Amsterdam University Press, Amsterdam.
Yearley, S., 2006. Bridging the science-policy divide in urban air-quality management: Evaluating ways to make models more robust through public engagement. Environ. Plann. C Gov. Policy 24 (5) 701–714.
Zinn, J.O., 2004. Social Contexts and Responses to Risk Network (SCARR) Literature Review: Sociology and Risk. University of Kent, Kent.