Expert views on scientific policy advice on complex environmental health issues

Perspectieven van wetenschappers op hun rol als beleidsadviseur
bij complexe milieu-gezondheidsvraagstukken
(met een samenvatting in het Nederlands)

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Say not, 'I have found the truth,' but rather, 'I have found a truth.'

— Kahlil Gibran, The Prophet

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General introduction

COMPLEX ENVIRONMENTAL HEALTH ISSUES

In the Western world everyone lives amidst a multitude of older and newer technologies such as fossil fuel powered engines for transport, antibiotics to treat bacterial infections and technologies using or emitting electromagnetic fields. These technologies are deeply engrained in modern society and influence our daily lives. In addition to the obvious benefits to individuals and society as a whole, there are also concerns about unintended negative health effects associated to the use of these technologies. Fossil fuel based emissions include fine particulate matter (PM) and greenhouse gases. Excessive use of antibiotics leads to the threat of increasing antimicrobial resistance (AMR). And there is concern among some parts of society on whether electromagnetic fields (EMF)—for example, used for diagnostic purposes in hospitals for MRI scans and by TV antennas, radio stations and mobile phone devices—may trigger negative health effects.

Modern technologies are typically used on a broad scale. They are in use for several decades or even centuries. When new technologies are introduced in society, research on possible health risks is relatively new and at best only data on the possible short-term effects are available (and these can also be limited, for example for EMF). In most cases, long-term effects, specific causal mechanisms, exposure and transmission routes or the effect of policies are unknown, and therefore uncertainties remain (for example for EMF, PM and AMR). Scientific uncertainty relates here to the limitedness or even absence of scientific knowledge (data, information), which makes it difficult to exactly assess the possible adverse health effects of complex environmental health issues and thus the need and effectiveness of possible policy measures to reduce these effects (Aven and Renn 2009).

This means that scientific research is usually not able to provide clear-cut answers to the request to quantify all environmental health risks. In many cases, scientists can only provide estimates and possible scenarios of (future) risks. Policymakers and experts have to deal with this remaining uncertainty about the possible health effects of complex environmental health issues. Against the background of scientific uncertainties inherent in such complex issues, experts are asked to provide policy advice. Scientific uncertainty provides leeway for different appraisal of risks. Experts may answer differently to questions as: How bad are the estimated health effects? Should we intervene? Or should we gather and await more information? How these risks are interpreted depends on the characteristics of who is being asked: their knowledge, their role (e.g. policymakers, scientific experts or the general public), and their personal values and attitudes.

Also, uncertainty can be exploited by stakeholders, either by claiming that policy measures are unwarranted because of a lack of proof, or by proclaiming the precautionary principle, given the scientific uncertainty (Van der

Sluijs 2005, Van Asselt and Vos 2006, Silva and Jenkins-Smith 2007, John 2010). Confusion about and distrust in science can easily be the consequence of different ways of presenting incomplete knowledge. This raises the question: What is the role of scientific experts when they are asked to provide policy advice?

BROADER DEBATE ON EXPERT ROLES

The position of scientific experts in the interplay between science and policy has been widely discussed, also outside the domain of complex environmental health issues. The scientific debate on roles of scientific experts is visible through publications in established journals addressing the issue (Tversky and Kahneman 1974, Giles 2002, Lancet 2002, Bal, Bijker et al. 2004, Oreskes 2004, Jasanoff 2007, Stirling 2010, Doubleday and Wilsdon 2012, Gluckman 2014), through movements such as Science in Transition (Dijstelbloem, Huisman et al. 2013), and by reports from international organizations such as the Organisation for Economic Co-operation and Development (OECD) and International Risk Governance Council (IRGC) (Felt and Wynne 2007, IRGC 2009, Jasanoff 2013, OECD 2015). The discussion revolves around the position of experts vis-à-vis policymakers and politics, especially when thinking about complex and uncertain risk issues such as the possible adverse health effects from electromagnetic fields, particulate matter and antimicrobial resistance.

Views on the working relationship between scientific experts and policymakers are changing over time. One of the (older) adages was "speaking truth to power" (Wildavsky 1979), referring to a clear division of tasks, i.e., scientists knew the truth, and politicians had the power. Newer adages object against this idea of a dichotomy of roles and describe a more continuous interaction between science, policy and other stakeholders (Wesselink, Buchanan et al. 2013). Certainly, scientific expertise is not the only source of information policymakers use when pondering about policy options and regulation. Modern risk governance emphasizes the continuous interaction of multiple players, including experts (Renn and Graham 2005, IRGC 2009, NRC 2009, Lebret 2015).

Where and when do expert roles matter in particular? The IRGC and others describe different types of environmental health issues: simple, uncertain, complex and ambiguous. This risk classification system can be used to determine the appropriate assessment and management strategy for an issue. For example, simple risks can be assessed and managed by experts (i.e., with a traditional risk assessment) whereas uncertain, complex and ambiguous risks are confronted with different legitimate viewpoints from which to evaluate whether there are or could be adverse effects and whether these risks are tolerable and acceptable (Klinke et al. 2011).

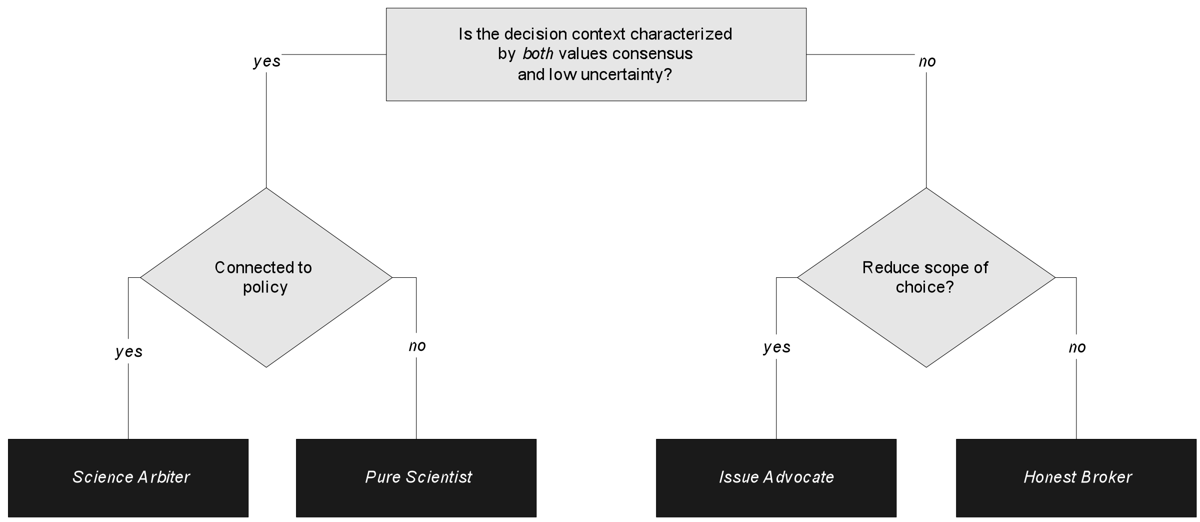
Besides the varying position of scientists vis-à-vis other stakeholders, experts can also differ greatly from one another in their viewpoints. When they hold different views on appropriate and proportional measures when scientific uncertainty remains, this could lead to considerable debate (within the expert community). 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—where there are threats of serious or irreversible damage the absence of proof does not justify inaction. Others have emphasized the absence of proof of adverse health effects and therefore have not implemented any policy interventions (Kheifets, Hester et al. 2001, Van Dijk, Van Rongen et al. 2011).

We argue that stakeholders, policymakers, and particularly scientists are not fully aware of where in the discourse, interpretative ambiguity (i.e., debate about the uncertainties in content itself) ends and personal views on roles, attitudes and values begin. This may confuse and cloud the debate and may lead to a lack of trust in science and experts. The topic of expert roles, therefore, merits further study. We also argue that such studies will be most informative when performed on complex and uncertain risk problems.

TYPOLOGIES OF EXPERT ROLES

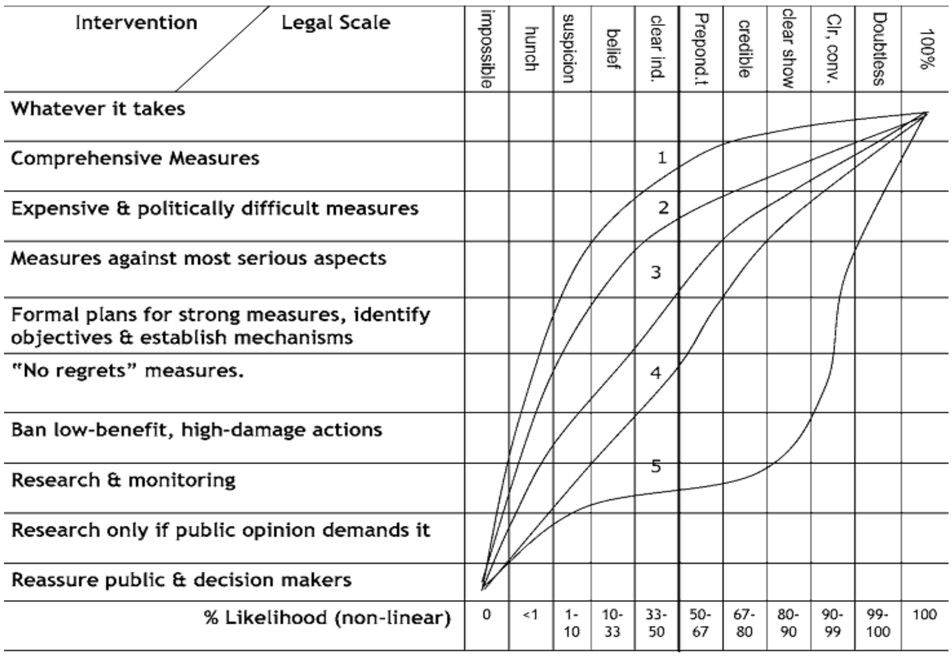
Scholars described different ways in which experts behave at the science–policy interface (Weiss 2003, Weiss 2006, Pielke Jr. 2007). Amongst others, Pielke and Weiss published typologies that address four and five roles, respectively, that experts can assume when providing policy advice. Central to their descriptions is the notion that scientists assume different expert roles in different situations. First, Pielke described the different roles that experts can play when interacting with policymakers in highly uncertain and politicized contexts, presenting his ideas by means of a typology. Pielke identifies four roles: the pure scientist, the science arbiter, the issue advocate and the honest broker of policy alternatives (see Figure 1 for criteria proposed by Pielke for the different roles of scientists in policy and politics). The *pure scientist* seeks to focus on only facts and does not interact with decision makers. The *science arbiter* answers specific factual questions posed by decision makers. The *issue advocate* seeks to reduce the range of choices available to decision makers by promoting one specific solution. Finally, the *honest broker of policy alternatives* seeks to expand or at least clarify the range of choices available to decision makers.

Figure 1. The criteria proposed by Pielke for the different roles of scientists in policy and politics (Pielke 2007).



Second, Weiss proposed a typology based on five positions that a scientist can take when addressing uncertainties. Central to Weiss' five roles is the assumption that experts differ in the assessment of the willingness and necessity to act on uncertain risks based on gradients in uncertainty on the one hand and supposed consequences on the other hand. Some experts may assert that any suggestion of an increase in risk is unacceptable and that the widespread use of (new) technologies should therefore be permitted only after thorough research has shown no evidence of adverse health effects. Weiss coined these experts' *environmental absolutists*. Other experts view risk as an inextricable part of innovation and accept the possibility of negative (side-) effects in the name of progress. Weiss used the term *scientific absolutists* to refer to these experts. In between these two extremes, Weiss identified the *cautious environmentalist*, the *environmental centrist* and the *technological optimist*. According to Weiss, his typology is intended to make it easier to separate technical discussions over the level of scientific uncertainty connected with scientific evidence, from the political and philosophical discussion of the degree of risk aversion to be applied in a particular case (Weiss 2003).

Figure 2. Weiss typology. The expected international action to address the shared danger of severe and irreversible harm is plotted as a function of the degree of scientific certainty and the degree of risk aversion. The probability scale is non-linear and asymmetrical.



Curves corresponding to different levels of risk aversion are represented as follows:

- Environmental absolutist
- Cautious environmentalist
- Environmental centrist
- Technological optimist
- Scientific absolutist

While both typologies share some elements, they actually describe different concepts. The *pure scientist* and the *scientific absolutist* indicate experts with a classical notion of science, i.e., the caricature of scientists that operate in an ivory tower with little or no interaction with politics or society, where only high scientific certainty can be a base for evidence-based policy. The other classes however differ; Pielke's typology focuses on the degree and extent of interaction between expert and policymaker, while Weiss describes the attitude toward justified intervention, given uncertainty and possible extent of impact of risks. In practice, perspectives from both typologies may simultaneously hold for a given expert for a given complex issue.

Pielke and Weiss based their largely theoretical typologies on personal observations. These typologies are useful in drawing attention to the topic by describing ideal-typical expert roles. They also provide a vocabulary to feed discussions on expert roles. However, there is a lack of empirical underpinning of these roles, that is, of the way experts actually see their own role and on the way they act in practice. Where theory can start and support discussion, empirical data can add insights into which role and viewpoint experts really hold and how frequent these different roles occur within groups of experts. In addition, empirical work can demonstrate to what extent experts from different disciplines or fields actually share or differ in dominant roles.

AIM AND RESEARCH QUESTIONS

The main goal of the research presented in this thesis is to empirically assess the existence of expert roles and viewpoints. The main research question is "*What are the different views of scientific experts on their role as policy adviser on complex environmental health issues?*" we also explore whether there are differences between scientific expert communities that study different complex environmental health issues.

The research question is studied in a three-pronged approach:

Chapter 2 presents a *pilot study* among Dutch experts on particulate matter and electromagnetic fields. The aim of this study is to empirically explore the existence of different roles among experts in the EMF and PM domains. The Dutch experts are a convenience sample selected from our existing networks of experts on these topics. Q methodology is used to identify and describe the different roles that PM and EMF experts can assume in their interactions with policymakers.

Chapter 3 presents the *literature review*. The objective of that study is to review publications on the subject of (factors that influence) the roles of scientists when advising policymakers on complex issues. A bibliometric approach is used to present a structured analysis of the interdisciplinary literature.

Three surveys amongst international experts in the fields of PM, EMF and AMR. The surveys are developed on the basis of the pilot study and literature review. A structured expert selection approach is adopted. The cases are selected to represent different types of environmental health issues and reflecting roles of different expert communities.

Chapter 4 presents the first case study on the issue of electromagnetic fields (EMFs). An expert consultation is conducted using Q methodology to test theoretical notions on the existence of different expert roles and to see what factors are associated with these roles. The main research question is: What are the different roles of EMF experts when they provide policy advice? The following sub-question is also addressed: What influences these differences? In addition, the effect of different roles on possible policy advice is explored.

Chapter 5 presents the second case study on the issue of particulate matter (PM). Again, an international expert consultation is conducted using the Q methodology. The goal is to empirically test theoretical principles on the existence of different expert roles and to analyze which roles actually play out in the domain of PM. Some factors are explored that are associated with these roles. The main research question explored is the following: What are PM experts' views on their roles when providing policy advice? Sub-questions are: Which factors are associated with the different roles identified and what effects do different expert roles have on policy advice.

Chapter 6 presents a comparison of three case studies on the issues of electromagnetic fields, particulate matter and antimicrobial resistance. These three case studies have been undertaken with as main research question: What are the different roles of EMF, PM and AMR experts when they provide policy advice? What are the main similarities and differences between expert roles in the fields of EMF, PM and AMR? The chapter summarizes and integrates findings of three case studies.

Finally, a general discussion (**Chapter 7**) presents some thoughts on the main findings presented in this thesis, how do these empirical findings relate to theoretical notions, and some methodological considerations i.e., strengths and limitations. This is followed by a discussion on the implications of our research findings for future research on scientific advice on complex environmental health issues.

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2

Different roles and viewpoints of scientific experts in advising on environmental health risks

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2013

ABSTRACT

Environmental health risks are often complex, large-scale, and uncertain. The uncertainties inherent in these problems permit differences among experts in the appraisal of risks. This raises the question of whether different expert roles exist and if so, how this affects the policy advice that is given. Here, we present a pilot study of the different roles and viewpoints that can be discerned among scientific experts in the Netherlands. Q methodology was used to empirically explore existing theoretical treatise on different expert roles. In total, 26 electromagnetic field (EMF) experts and 21 particulate matter (PM) experts participated. The responses were analyzed separately for EMF and PM respondents using Q factor analysis. In both the EMF and PM domain, three different expert roles were identified. This suggests that particular expert roles depend on the specific environmental health risk. The results indicate that different expert roles exist among scientists who provide policy advice on environmental health risks. This empirical study adds new data and insights to the literature on expert roles. The results of this study are relevant for the selection and composition of expert committees and the interpretation of expert advice.

KEYWORDS

Expert roles, scientific policy advice, environmental health risks, particulate matter, electromagnetic fields, Q methodology.

1. INTRODUCTION

The advisory role of scientific experts in the field of environmental health is subject to scientific and public debate [1, 2]. Public doubt concerning the role of scientific experts is regularly expressed, as occurred recently during the IPCC "Climategate" incident and the Mexican flu outbreak, for example. Scientifically, this debate has been ongoing for decades [3, 4]. Several scholars have discussed the various potential roles of experts in the interplay between science and policy. Wildavsky's [5] famous phrase "speaking truth to power" suggests a clear division of tasks between science and politics. According to Wildavsky, scientific experts should communicate objective and true knowledge to politicians. Jasanoff [6], however, states that "the notion that scientific advisors can or do limit themselves to addressing purely scientific issues seems fundamentally misconceived", because the idea of the completely value-free scientist is outdated and the relationship between science and policy is intricate. These competing positions point to the dilemmas that scientists often face in their interactions with policymakers, as well as to the tension between science and policymaking in general [7].

Discussions about the position of scientific experts in the policy process are especially likely to occur when knowledge is incomplete, the research subject is highly uncertain and ambiguity of values exists. These properties characterize many modern environmental health risks, which are complex problems embedded in wider environmental, social, economic and political systems [8-14]. The WHO defines environmental health risks as "all the physical, chemical, and biological factors external to a person, and all the related factors impacting behaviours. It encompasses the assessment and control of those environmental factors that can potentially affect health" [15].

In many cases, policymakers are required to make decisions even when the available data are scarce, uncertain and contradictory, because the effects of environmental health hazards may turn out to be irreversible before conclusive scientific evidence becomes available [16, 17]. Hence, pressure exists on scientific experts to give advice, even when substantial scientific uncertainties and ambiguity of values remain. Our interest lies in the roles of scientific experts and the tension that results from the combination of uncertain knowledge with a societal demand for clear policy advice. In the present paper, we examine the ways in which scientific experts cope with this tension, with an empirical focus on the topics of electromagnetic fields (EMFs) and particulate matter (PM).

Electromagnetic fields (EMFs) are produced by a variety of natural and man-made sources. EMFs are characterized by their frequencies and associated wavelengths. Important anthropogenic EMFs are the static fields and extremely low frequency fields (typically 50 or 60 Hz) associated with electricity production, transport and use in appliances and radio frequency fields (ranging from 300 Hz to 300 GHz and used in applications such as mobile communication, WiFi, DECT phones, radio and television transmission, and radar). Many EMF sources have proliferated rapidly over the past few decades (e.g., DECT and cell phones and associated base stations, WiFi, radiographic baby phones and remote controls). The health effects of EMFs at high exposures are well documented, but at exposure levels that are currently typical for the general population, there is insufficient scientific evidence of adverse health effects. Effects reported at lower exposures in some studies (but not in others) differ in nature from effects observed at higher levels. Currently, the scientific community is highly divided on whether EMFs represent a health risk [18].

The second domain considered in this study, particulate matter (PM), consists of a complex mixture of airborne particles of various diameters, chemical compositions and physical properties. PM may be natural (e.g., suspended sea salt, soil dust, pollen) or may result from human activity (e.g., industry, energy production, transport). There is ample scientific evidence for adverse health effects of PM at exposure levels that are currently typical among the general population [19].

The health effects of both EMFs and PM are subject to public and scientific debate. The debate concerning EMFs focuses on whether a causal relationship exists between exposure and possible adverse health effects at exposure levels that are experienced by the general population. The debate about PM mainly concerns the health impacts of different particle types, the underlying causal mechanisms and the nature of the exposure-response relationship for various health endpoints. Linked to these debates is the question of whether (precautionary) policy measures can be taken and if so, what these measures are.

Multiple scholars, including Pielke and Weiss [20-24], have discussed whether all experts give advice in the same way or whether different experts assume different roles. Pielke and Weiss have each described in a theoretical manner the different ways in which experts might cope with complex environmental health risks. Central to their descriptions is the idea that scientists assume different expert roles in different situations. Pielke described the different roles that experts can fill when interacting with policymakers in highly uncertain and politicized contexts, presenting his ideas by means of a typology (see Figure 1a). Some scientific experts believe that their role is primarily to conduct research and not to engage in intensive contact with policymakers. These experts are likely to present their research questions and results differently than do scientists who believe policy-relevant knowledge, i.e. science that answers specific policy questions, to be most important. Pielke distinguishes four roles: the pure scientist, the science arbiter, the issue advocate and the honest broker of policy alternatives. The *pure scientist* seeks to focus only on facts and has no interaction with the decision maker. The *science arbiter* answers specific factual questions posed by the decision maker. The *issue advocate* seeks to reduce the range of choices available to the decision maker by promoting one specific solution, and finally, the *honest broker of policy alternatives* seeks to expand, or at least clarify, the range of choices available to the decision maker.

Weiss proposed a typology based on five positions that a scientist can take in dealing with uncertainty. Each position represents an attitude that is the result of a given level of uncertainty in combination with differences in the perceived necessity to take measures and the willingness to do so, given the associated (societal) costs (see Figure 1b). Some experts might assert that any suggestion of an increase in risk is unacceptable and that the widespread use of new technologies should therefore be permitted only after thorough research has shown that there is no adverse health effect. Weiss termed these experts *environmental absolutists*. Other experts see risk as an inextricable part of innovation and accept the possibility of negative (side-) effects in the name of progress. Weiss used the term *scientific absolutists* to denote these experts. In between these two extremes, Weiss positioned the *cautious environmentalist*, the *environmental centrist* and the *technological optimist*.

Thus far, there has been little empirical evidence to support the proposed typologies. By empirically exploring the existence of different expert roles, the current study extends the existing knowledge about expert advice and policymaking. Our overall aim is to empirically explore the existence of different roles and viewpoints among experts in the EMF and PM domains and to do so against the background of scientific and public debates on environmental health risks. The following questions have guided us throughout our research:

- Do different experts have different roles when interacting with policymakers about environmental health risks?
- Do EMF and PM experts differ in how they interpret evidence and advice concerning environmental health risks?
- To what extent do these different roles correspond with the elements of Pielke's and/or Weiss' typologies?

2. METHODS

2.1 Q methodology

Q methodology was used to explore the presence of different expert roles in the field of environmental health (for an extensive description of the history, function and reliability of Q methodology, see [25-28]). Q methodology was developed in the 1930s as a technique for studying human subjectivity [29]. This technique involves asking participants to sort a number of statements based on their personal level of (dis)agreement with the statements. The resulting Q sorts, which represent the viewpoints of individuals, are used to identify clusters of shared ways of thinking that exist among groups of people [30]. These clusters are identified statistically using Q factor analysis. An important assumption in Q methodology is that a limited number of distinct clusters exist for any particular topic [25]. The methodology has only recently become more frequently used by researchers [31], particularly in the domain of environmental studies [32].

2.2 Q sample

The 39 statements included in the Q sample (see Appendix) were compiled by the authors based on the published literature (including the work of Pielke and Weiss) and input provided by colleagues working in the respective scientific domains. The statements were numbered randomly. Thirty-four of these statements were exactly the same for both of the domains, with the abbreviations EMF and PM interchanged. The other five statements were related to concrete policy measures and were therefore domain-specific. The balance, clarity and simplicity of the Q sample were pre-tested with the help of three respondents who did not take part in the final study.

2.3 Participants and data collection

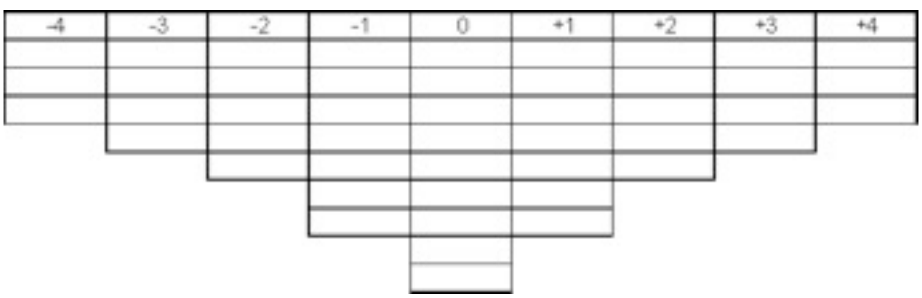
Dutch experts were selected based on their knowledge of the scientific discourse and professional activity on either one of the two specific research domains (EMFs and PM). Their expertise is evident from research activities (the majority holds a Ph.D.), scientific publications and/or scientific advisory activities. The recruitment process consisted of contacting the members of Dutch national committees, researchers at Dutch universities and other scientific institutes and additional experts identified through the network of the Dutch National Institute for Public Health and the Environment (RIVM). We approached 38 EMF experts and 49 PM experts by mail. After a week, non-respondents received one reminder. In total, 26 EMF experts and 21 PM experts participated (response rates: EMF = 68.4% and PM = 42,9%). Table 1 shows selected background information on the participants, including scientific background (i.a. physics, chemistry, medicine, epidemiology, biology, environmental sciences and psychology) and number of years in the field.

Table I. Background information on participants.

	EMF	PM
Age (average)	47 *(st dev 10)*	47 *(st dev 8.5)*
Number of years in field (average)	1.8 *(st dev 0.4)*	8.4 *(st dev 8.8)*
Scientific background	Natural & Social Sciences	Natural Sciences
Gender (m/f)	20/6	17/4

Data collection was conducted in May 2010 using the web-based program FlashQ. For the sorting exercise, participants were asked to read the statements and score them according to a forced quasi-normal distribution ranging from -4 (most strongly disagree) to +4 (most strongly agree), with a middle column representing 'neutral' or 'do not know' (see Figure 2). Additional open questions about the motivation behind the scoring of the statements gave us further insight into the reasoning and motivations of the participants.

Figure 2. Example of score sheet for the Q sort (quasi-normal distribution).



2.4 Statistical analysis

PQMethod software (version 2.11) was used to analyze the correlation and factoring of the Q sorts. A Q sort consists of the complete rank ordering of the statements as scored by one participant. First, a statistical correlation summarizes the similarities in views among participants. Q factor analysis then identifies clusters of similar viewpoints. Subsequently, a characteristic Q sort distribution is calculated for each factor based on the standardized factor scores. This distribution reveals the statements that are scored similarly in each cluster and therefore gives an idea of the common viewpoint represented by each factor. The 26 EMF sorts and the 21 PM sorts were analyzed separately but in an identical manner. The sorts and the statements were correlated in an n-by-n matrix. Centroid factor analysis was conducted on each matrix using PQMethod [26]. Three factors were distinguished for each domain based on the following three criteria conventional in Q methodology: (1) factors with eigenvalues above 1 were considered significant [25, 33], (2) each group contained at least three experts, and therefore, only factors with three or more significant loadings were considered (note that with Q, persons rather than statements load on each factor) and (3) an explained variance of over 4 percent was considered acceptable. The analysis' sensitivity was tested by changing the eigenvalue, shifting the percentage explained variance boundary, increasing/decreasing the minimum number of sorts, and analyzing both datasets together. Varimax rotation [34] was used to obtain a clear pattern (simple structure) of factor loadings such that factors were clearly characterized by a small number of high loadings for some variables and a large number of zero or small loadings for others. The vast majority of sorts loaded on one factor, but we also found sorts that were not significantly associated with just one factor. Two EMF sorts and one PM sort loaded on several factors; these can be seen as hybrids of the derived factors. As is common with the Q method, these sorts were set aside during the interpretation phase, although we are aware of their existence.

We interpreted the factors based on both the computed composite factor scores and the so-called distinguishing statements. Given three factors X, Y and Z, a distinguishing statement for factor X is a statement that received a score in factor X that is significantly different from the corresponding score in factors Y and Z. An example of a distinguishing statement is EMF statement 15 (see Table A), which states that an expert has a choice in the way he or she presents scientific knowledge to a policymaker. Of the three factors that we found among EMF experts, the experts in factor 2 hold a very different point of view regarding statement 15 compared to the experts in factor 3, as is shown by the average scores for this statement of *plus* 3 (strongly agree) in factor 2 and *minus* 3 (strongly disagree) in factor 3.

3. RESULTS

In each of the two domains, three distinct factors were distinguished. The extracted factors yield total explained variances of 57 percent in the EMF domain and 51 percent in the PM domain. The full list of statements with associated factor scores is presented in the table in the Appendix. Although the number of extracted factors is the same for both domains, the factor loadings and thus the meanings of the factors differ between the two domains. Each of the two groups of three factors will be discussed separately in relation to the typologies of Pielke and Weiss. In line with these typologies, the factors are here referred to as 'roles'.

3.1 Electromagnetic field experts

Although the level of agreement with most of the statements in the Q sample varied among experts, there was consensus on a few of the statements. For example, all of the experts disagreed with the statement that EMFs are a danger to public health (statement 26). Not a single expert agreed that exposure to EMFs from cell phones causes brain tumors (statement 33) or that we should drastically reduce the overall exposure of the population to EMFs (statement 36). All of the EMF experts strongly agreed with the statement that risks to public health and the environment have always existed and will always remain (statement 24). Finally, most of the experts did *not* agree that EMFs represent an uncertain risk (statement 7). From the pattern of responses, three clusters of viewpoints emerged. We interpreted these as representing Role A: the *autonomous scientist*, Role B: the *pragmatist expert* and Role C: the *action-oriented expert*.

3.1.1. Role A: The autonomous scientist

The *autonomous scientist* role was shared by 9 participants and explained 25% of the total variance. This role is characterized by a belief in the strict separation of science and policy. This role emphasizes that scientists are sources of pure scientific knowledge (statements 4, 8, 21, 28, 29, and 30; see table 2) and highlights the opinion that science should contribute to the solution of social problems (statement 12). Put differently, this role reflects the belief that science must contribute to society but that it should do so without intense deliberation between scientists and policymakers (statements 1 and 13). Scientific findings should incite action or new policies (statement 13), but at the same time, the interaction between scientist and policymaker should be unidirectional (namely, from the scientist to the policymaker).

The *autonomous scientist* role expresses the belief that EMFs do not pose a real threat to public health and the environment (statement 26). The perception of the participants is that we do not need to bring down the overall exposure of the general public to EMFs (statements 36, 38, and 39). In line with this, precautionary policies are not considered necessary (statement 19). More concretely, the government should not dissuade children from using cell phones (statement 31), and according to the experts in this role, EMFs do not increase the risk of developing a brain tumor (statement 33). Additionally, these experts believe that disagreement exists among their peers about the definition of the problem and how to tackle it (statements 5 and 6). The 9 participants who scored high on the role of the *autonomous scientist* do not think that there are certainly health risks of EMFs, but they do agree that there is a lot of certainty in our current knowledge about EMFs. In line with this, the *autonomous scientist* believes that there is no need for more research. (S)he thinks that it is adequate to monitor current and future developments in this domain. In the *autonomous scientist*, elements of Pielke's *science arbiter* and *pure scientist* types (both of which support a low level of science-policy interaction) are found. In addition, Weiss' *scientific absolutist* type (take no action until EMFs are proven to be damaging) is found in this role. Taking all of this into account, we have termed this role the *autonomous scientist* because the participants strongly value a strict separation between science and policy and thus support the autonomy of scientists.

3.1.2. Role B: The pragmatist

The *pragmatist* role was shared by 12 participants and explained 23% of the total variance. This role is characterized by participants who do *not* seek a strict separation between science and policy (statements 9, 4, and 8). This is in contrast to the role of the *autonomous scientist* (as is also shown by a Pearson's correlation of -0.61 between the factor scores for Roles A and B). The *pragmatist* emphasizes that scientific information is often used as a strategic resource in ideological debates (statement 11) and highlights the opinion that a scientific expert can choose how to present scientific knowledge to policymakers (statement 15).

The pragmatist participants disagreed with statements 5 and 6, indicating that they believe that disagreement exists among EMF experts about the definition of the problem and how to tackle it, although this opinion was not as strong in this role as it was in the *autonomous scientist* role.

The *pragmatist* role is found to be directly opposite to elements of Pielke's *pure scientist* and *issue advocate* types (both of which support the minimization of the range of choices available to the policymaker), as the *pragmatist* believes that experts should *not* reduce the range of choices available to policymakers. None of Weiss' types are convincingly found in the *pragmatist* role, but this role points in the direction of the *environmental centrist* type (statement 18).

We have termed this role the *pragmatist* because the participants who scored high on this role appear to support a turn towards concreteness and adequacy. These participants are aware of the different ways in which knowledge can be used (e.g., strategically, informatively, or deliberatively) and believe that it is the expert who chooses between these options. The *pragmatist* believes that interaction between science and policy is inevitable and necessary.

Table II. Statistics related to roles in the electromagnetic field sub-domain.

	ROLE A: THE AUTONOMOUS SCIENTIST	ROLE B: THE PRAGMATIST	ROLE C: THE ACTION-ORIENTED EXPERT *(C1: Overseer and C2: Proactive Expert)*
N	9	12	3
Explained variance (%)	25	23	9
Statements most strongly agreed with (+3 and +4)	16, 21, 28, 29, 30	1, 11, 12, 15, 24	1, 12, 14, 24,37
Statements least strongly agreed with (-3 and -4)	5, 6, 26, 33, 36	6, 9, 26, 33, 38	15, 26, 31, 33, 36

3.1.3. Role C: Action-oriented expert

The *action-oriented* role was shared by 3 participants and explained 9% of the total variance. Important to note is that within the role of the *action-oriented expert,* 2 participants sorted the statements in one order and 1 participant sorted them in the reverse order. For example, a statement about dissuading cell phone use by children was given a factor score of plus 3 by the first two participants and a factor score of minus 3 by the third participant. Hence, this role is a “bi-polar role” with two opposing viewpoints on the same axis, which makes it necessary to distinguish two sub-roles (Role C1: the *overseer* and Role C2: the *proactive expert*). The common denominator for all three action-oriented experts is a position on the continuum of action perspectives, though these experts differ in which action they consider to be the most appropriate.

C1: The *overseer* perceives the monitoring of concentrations and possible health effects as an appropriate policy approach in the EMF domain, as the factor score for statement 37 illustrates. This role expresses the beliefs that consensus exists among experts about the extent of the problem (statement 6) and that experts agree on the most suitable measures to take (statement 5). In line with this, the *overseer* role is characterized by the belief that there is little uncertainty regarding the risks of EMFs to public health. This role emphasizes that there is no need for more research in this domain (statement 32) and highlights the opinion that the government should not take active measures (e.g., advise children to minimize the use of cell phones (statement 31)). We have termed this role the *overseer* because these participants appear to believe that the EMF domain must be monitored but that, at the moment, this domain is under control and intervention is unnecessary.

C2: The *proactive expert* is on the same axis as the *overseer* but at the other end, which means that these two roles hold opposite views. Whereas the *overseer* believes that the monitoring of developments is an appropriate policy approach, the *proactive expert* thinks that precautionary action is necessary and that all options should be presented to policymakers. Furthermore, the proactive expert beliefs that there is no consensus among experts about the extent of the problem nor on the most suitable measures to take.

3.2 Particulate matter experts

All of the PM experts strongly disagreed with statements 22 and 23, which state that measures should be taken to protect public health only when irrefutable scientific evidence is available. All of these experts shared the belief that the development of new sources of PM should be impeded (statement 22). The experts agreed that the current Dutch standards for PM are debatable and that PM levels under the current standards do not necessarily mean that there are no health effects (statement 34). Finally, there was strong agreement among the experts that research should contribute to solving societal problems (statement 12).

Based on the pattern in the responses of these experts, we distilled three roles within the PM expert group. These will be described as Role 1: the *engaged expert*, Role 2: the *instrumental expert* and Role 3: the *deliberator*.

3.2.1. Role 1: The engaged expert

The *engaged expert* role was shared by 7 participants and explained 20% of the total variance. This role is characterized by the idea that the government should take precautions to reduce PM emissions (statements 39 and 18) and that merely monitoring developments is not a sufficient approach (statement 37). Furthermore, the role emphasizes that we should not act on natural sources of PM such as windblown dust, sea spray and wildfires (statement 33) and highlights the opinion that there is agreement among scientific experts on the nature and extent of the problem (statement 6). The *engaged expert* participants disagreed with the statement that finding truth is the only objective of science (statement 8) and agreed with the idea that scientific experts have a choice in how they present scientific knowledge to policymakers (statement 15).

The *engaged expert* role is found to be opposite to Pielke's *pure scientist* and *science arbiter* types. Elements of Weiss' *environmental absolutist* type are found in the *engaged expert*, as these participants expressed agreement that precautionary measures are the most appropriate policy approach. We have termed this role the *engaged expert* because the participants who scored high in this role appear to be strongly convinced that PM is an important issue that deserves attention from science and policy.

3.2.2. Role 2: The instrumental expert

The *instrumental expert* role was shared by 6 participants and explained 16% of the total variance. This role is characterized by the belief that scientists should maximize the range of choices available to policymakers. Correspondingly, these participants strongly disagreed with the idea that a scientist should select any particular type of knowledge to present to a policymaker (statement 10). The *instrumental expert* role highlights the opinion that PM is an uncertain risk (statement 7) but that despite the uncertainty, the government should not follow the 'standstill principle' (statement 38). Indeed, monitoring developments is the most appropriate approach (statement 37) according to this group. This is opposite to the viewpoints of the *engaged expert* and the *deliberator* (as is also evident from a Pearson's correlation of -0.49 between the factor scores for Roles 1 and 2).

Typical of the *instrumental expert* is the belief that science should not be separated from policymaking (statement 8). This role is found to be opposite to Pielke's *pure scientist* and *issue advocate* types. Indeed, *instrumental expert* participants agreed with the idea that a scientific expert should expand the range of choices available to a policymaker. This point of view corresponds to that of Pielke's *honest broker of policy alternatives*.

We have termed this role the *instrumental expert* because these experts consider monitoring to be an appropriate policy approach even though they believe that PM represents an uncertain risk. This points towards the support of instrumental action, i.e., the implementation of measures when necessary but not the direct implementation of every possible solution.

Table III. Statistics related to roles in the particulate matter sub-domain.

	ROLE 1: THE ENGAGED EXPERT	ROLE 2: THE INSTRUMENTAL EXPERT	ROLE 3: THE DELIBERATOR
N	7	6	7
Explained variance (%)	20	16	15
Statements most strongly agreed with (+3 and +4)	12, 18, 20, 33, 39	12, 14, 16, 30,37	1, 12, 14, 16, 28
Statements least strongly agreed with (-3 and -4)	9, 22, 23, 27, 34	8, 10, 22, 23, 34	9, 22, 23, 34, 37

3.2.3. Role 3: The deliberator

The *deliberator* role was shared by 7 participants and explained 15% of the total variance. This role is characterized by the belief that monitoring current and future developments is not sufficient (statement 37). Instead, the role emphasizes that scientific experts should deliberate with policymakers about different policy options (statement 1). According to this role, the deliberation i.e. dialogue itself is important. The *deliberator* does not support the precautionary principle per se (statements 19, 24, and 18) and does not strongly agree with the idea that commotion or anxiety amongst civilians is a good motivation for action (statement 3). According to this role, the scientist is the one who presents the facts, and politicians must decide how these facts should be used to guide policy (statement 29). Contrary to the *engaged expert* and the *instrumental expert*, who have relatively neutral positions, the *deliberator* considers knowledge presented by laymen to be less valuable to policymakers than knowledge presented by scientific experts (statement 28).

The *deliberator* is a clear example of the type that Pielke called the *honest broker of policy alternatives*. The emphasis of this role is on a broad dialogue, and because of this, we have termed this role the *deliberator*.

3.3. Comparison between electromagnetic fields and particulate matter

The three roles distinguished among the EMF experts are different from the three roles found among the PM experts. Overall, we see a divide in the interpretation of the knowledge bases of the two domains: EMF is interpreted as a certain risk problem (i.e., EMFs are believed to present no health risk to the general population), and PM is interpreted as an uncertain risk problem (i.e., PM is believed to present a health risk to the general population). We recognized elements of Pielke's *pure scientist* and *science arbiter* primarily among the EMF experts and elements of the *issue advocate* and the *honest broker* primarily among the PM experts. Weiss' typology can be seen as a continuum ranging from the *scientific absolutist* to the *environmental absolutist*. Both extremes were observed in the present study. The *scientific absolutist* was found among the EMF experts and the *environmental absolutist* was found among the PM experts. None of the middle positions on Weiss' continuum were clearly identified among the respondents in the present study. Nonetheless, the *pragmatist* (Role B) in the EMF domain indicates that some experts do assume a more intermediate role.

4. DISCUSSION

In this study, Q methodology was used to identify and describe the different roles that environmental health experts can assume in their interactions with policymakers. The aim of this study was to empirically explore the existence of different roles among experts in the EMF and PM domains, with reference to the typologies of Pielke [22] and Weiss [24, 35].

We found three distinct roles in each expert group that met the selection criteria applied in the factor analysis. In the EMF domain, the roles of the *autonomous scientist*, the *pragmatist* and the *action-*

oriented expert were recognized. In the PM domain, we distinguished the roles of the *engaged expert*, the *instrumental expert* and the *deliberator*. These six roles are considered to represent hybrids of the expert roles proposed by Pielke and Weiss.

Due to the exploratory nature of this study, the results presented here have some limitations. First, in the development of the Q sample, we referred most heavily to the typologies of Pielke and Weiss because those typologies are well elaborated. As a consequence of the ideal-typical nature of the roles postulated by Pielke and Weiss and due to the fact that we combined statements relating to both of those typologies in one Q sample, it may not be surprising that we found combinations of Pielke's and Weiss' roles. However, other theoretical treatises on expert roles exist: for example, see Hisschemöller and Hoppe (20, 36) and Funtowicz and Ravetz (37). In addition, we cannot rule out the possibility of some differences in interpretation between our statements and the original theories. Future research might tease out explicit differences between the theoretical concepts of Pielke and those of Weiss or merge them into an overarching model.

A second limitation of the present results is that additional elements may affect the role that an expert takes in a certain debate, such as the costs of interventions, equity and the impact on social unrest. Experts may also take the effect on future funding opportunities into account as well as their previous experience with giving policy advice and their relationships with other committee members. These elements would require extensive further assessment, which was outside the scope of the current study.

Third, the methodological choices in our study regarding the number of respondents, the selected eigenvalue cut-off of 1, the 4 percent explained variance criterion and the minimum number of sorts loading on a factor are conventional in Q methodology but somewhat arbitrary. Different choices might have led to some differences in the results, which is why we cannot claim that we found definitive invariable factors. We have tested the sensitivity of our analysis in a number of ways: changing the eigenvalue, shifting the percentage explained variance boundary, increasing/decreasing the minimum number of sorts (i.e., number of experts sharing a common view), and analyzing both datasets together (results not shown here). Increasing the minimum number of sorts to 4 would eliminate one factor, Role C. A minimum of 3 sorts per factor is the common cut-off point in Q methodology studies (38) and increasing that number would mean loss of information (Role C). All other methodological changes that we have analyzed did not affect the results. The sensitivity analysis indicated that the results are rather robust. We have not performed a follow-up of non-responders in our study and thus do not know their motives. After one reminder, the response rate for PM was 43%. Potentially, experts with views other than mainstream may have been under- or overrepresented. Though there is no indication of bias concerning the final set of respondents, in future applications the use of a more formal expert nomination and selection procedure such as the one proposed in the expert elicitation model by Knol et al. [39] could structure the selection process and improve its transparancy. There was a difference in the number of years that EMF and PM experts work in their field, reflecting the different histories in environmental health research. PM has a long research history in the Netherlands (going back to the 1960s), while Dutch EMF research is of a more recent date. Therefore, EMF experts on average work fewer years in their field.

Finally, in the present study, not all of the sorts (i.e., experts) loaded significantly on one factor; some sorts loaded on multiple factors. Our interpretation is that not all experts fit one particular (theoretical) role and that, instead, some experts adopt parts of different roles. The presence of these hybrids makes us aware that any theoretical distinction may leave some people and positions unaddressed. Collins and Evans [40] argue that all categorizations of expertise will be flawed because such categorizations involve “ideal types”, when in reality, cases will exist in which one kind of expertise shades into another. Despite this, our study provides a structured reflection on expert roles at a time when the position of experts is publicly contested. We empirically observe elements of previously proposed expert role typologies, although it appears that the typologies are not fully empirically corroborated. This may also be due to the way this exploratory study has been set up. Nevertheless, we consider it valuable to use the existing typologies to inform discussions about expert roles.

Further empirical work can eventually improve our understanding of expert roles, with potential implications for the way expert advice is organized. For example, the processes of selecting individual advisory experts and assembling advisory panels and committees may be re-examined once the existence of different expert roles is confirmed. The selection of experts in advisory bodies often varies due to the historical contexts in which they were established [2]. Experts are generally selected based on a set of criteria such as their individual knowledge base (discipline), their status as authorities within their discipline and willingness to put their knowledge at society’s disposal in a disinterested way [4141]. This paper adds as possible criteria the different roles held among experts. Eventually, teams of experts, with members holding roles that are sufficiently representative of the divergent roles in the expert community, could provide more balanced advice and input for policy assessment and policymaking. While consensus advice is desirable where possible, it is generally believed that dissenting views should be made explicit to fully acknowledge pertinent uncertainties. Whether such reporting is possible is however dependent on e.g., the type of advice that a committee has been asked to give.

To our knowledge, this is the first empirical study on the advisory roles of scientific experts in the field of environmental health. The overall result is that some elements of the ideal-typical roles distinguished theoretically by Pielke and Weiss are indeed supported by our empirical data. However, the roles found empirically in the present study do not completely correspond to those ideal-typical definitions. Moreover, we found some differences in roles between the experts in the EMF domain and those in the PM domain. These may reflect genuine differences, but this must be confirmed in further research. We observed that none of the roles described here were identical in both of the domains, but some overlap exists between the roles in the two domains. Within this study, we cannot rule out an effect of statistical variation stemming from the sampling of experts from two different domains. Overall, we conclude that the existence of different expert roles is evident from the empirical data presented here. However, given the exploratory nature of our study, our findings must be replicated on a larger scale before conclusions can be drawn about the observed differences between the roles identified in each of the two domains and between these and the roles previously described in the literature. Moreover, additional empirical work is needed to determine the cultural elements, context-specificity and variation over time of expert roles. Following this idea, we note that research in the domains of EMF and PM is dynamic in nature and, consequently the responses to our statements provide a snapshot that could change when new scientific insights arise.

In conclusion, this pilot study on expert roles is the first of its kind and reveals significant differences in roles among experts, particularly regarding agreement about the necessity and utility of different action perspectives on policy intervention.

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APPENDIX

Table A. Factor arrays and factor Q sort values for each statement

		EMF Experts			PM Experts		
	Statements (with EMF and PM interchanged)	ROLE A: THE AUTO-NOMOUS SCIENTIST	ROLE B: THE PRAG-MATIST	ROLE C: THE ACTION-ORIENTED EXPERT *(C1: Overseer, C2: Proactive Expert)*	ROLE 1: THE ENGAGED EXPERT	ROLE 2: THE INSTRU-MENTAL EXPERT	ROLE 3: THE DELI-BERATOR
1	As an expert, I see it as my job to initiate deliberation with policymakers (and vice versa).	-1	3	3	1	0	3
2	As an EMF/PM expert, I see it as my duty to recommend specific policy actions.	0	0	2	1	0	1
3	Anxiety reduction in civilians is a good motivation to take action in the case of scientific uncertainty.	-1	-1	-1	-2	-1	1
4	Science should only be about the systematic collection of knowledge.	2	-2	0	-2	-1	-2
5	EMF/PM experts agree on the measures to be taken to reduce the health risks of EMF/PM.	-3	-2	1	0	-2	-2
6	There is complete consensus among EMF/PM experts on the nature and extent of the problem.	-4	-3	2	2	-1	-2
7	Uncertainty about the risks of EMF/PM is high.	1	0	-1	-1	1	-1
8	Truth is the only purpose of science; policy purposes are irrelevant for science.	2	-1	0	-2	-3	1
9	As an expert, I seek strict separation between science and policy. Therefore, I have minimal contact with policymakers.	0	-3	1	-3	-2	-4
10	Scientists should present their own selection of knowledge to policymakers.	-1	-1	-2	-1	-4	0
11	Science is often used as a strategic resource in ideological debates.	0	3	2	-1	1	-1
12	I think it is important for scientific research to contribute to solving societal problems.	2	4	3	3	3	3
13	Science should incite action, such as taking concrete policy measures.	1	0	1	1	1	0
14	As an expert, it is my responsibility to fully inform decision makers about the available policy alternatives.	1	2	4	0	4	4
15	As an expert, I have a choice in how I present my knowledge or assessment to policymakers.	0	3	-3	1	-1	-1
16	It is up to politics to decide whether the costs associated with a particular measure are reasonable.	3	2	0	1	3	4
17	I think it's better to be safe than sorry.	0	0	0	1	0	1
18	When the public health and environmental consequences of a project are uncertain, the benefit of the doubt must be given to people and to the planet.	1	1	-1	3	-2	0
19	Even though the effects of EMF/PM are highly uncertain, the government should advise individuals and businesses to take precautionary action.	-2	-1	0	0	0	-1

20	Technological innovation will reduce the adverse health effects of EMF/PM.	0	1	0	3	2	0
21	New EMF/PM policies should be based only on scientific evidence or at least on the best available knowledge.	4	2	2	0	-1	1
22	Given the lack of solid scientific evidence, there is no reason to impede the development of specific EMF/PM sources.	0	1	1	-4	-4	-3
23	Measures should be taken only if conclusive evidence that EMF/PM is harmful to public health becomes available.	-1	-1	-1	-4	-3	-4
24	Environmental health risks have always existed and will always remain.	2	4	3	2	2	-1
26	EMF/PM poses a major threat to public health.	-4	-4	-4	2	1	0
27	Lack of clarity about appropriate EMF/PM policies is caused primarily by disagreement among experts.	-2	-1	-1	-3	-2	-2
28	All things considered, the knowledge of lay people is less valuable for politicians and policymakers than the knowledge of scientists.	3	-2	1	-1	-1	3
29	Scientists deal with the facts, and politicians deal with the policy implications of these facts.	4	0	1	-1	0	2
30	When there is insufficient knowledge, politicians should decide how to deal with uncertainty.	3	2	-2	-2	4	2
32	I think that investing in more research is a sensible policy approach with proportional costs, given the risks and uncertainties about the effects of EMF/PM at current levels.	1	1	-2	0	2	2
36	Given the high uncertainty about the effects of EMF/PM at current levels, I think that drastic exposure reduction is a sensible policy approach with proportional costs.	-3	-2	-3	0	0	0
37	Given the high uncertainty about the effects of EMF/PM at current levels, I think that monitoring of developments is an effective policy approach with proportional costs.	1	1	4	-2	3	-3
38	Given the high uncertainty about the effects of EMF/PM at current levels, a powerful 'standstill principle' should be applied.	-2	-4	-2	0	-2	0
39	The government should take precautionary measures to reduce exposure.	-1	0	-2	4	1	2
	Specific EMF statements						
25	People who do not want to be exposed to EMF should just move.	-1	-2	0			
31	I think we should implement a measure to discourage children from using cell phones.	-2	0	-3			
33	Cell phones probably cause brain tumors.	-3	-3	-4			
34	It is necessary to set standards that protect employees from frequent EMF exposure.	2	2	2			
35	It is hypocritical to take precautionary measures for new pylons while old ones may simply persist.	-2	1	-1			
	Specific PM statements						
25	I think we should introduce a compulsory particle trap for diesel engines.				2	1	2
31	I think there should be a regulatory standard for particles smaller than PM10, say a PM2.5 standard.				2	2	-1
33	PM originating from sea salt is a natural phenomenon that we should not seek to reduce.				4	2	1
34	PM concentrations under the current policy standard imply a healthy environment.				-3	-3	-3
35	Lowering the speed limit for road traffic has a positive effect on public health; therefore, it is a desirable policy measure.				-1	0	-2

3

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

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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, Hester et al. 2001, Van Dijk, Van Rongen 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; Mitroff and Sagasti 1973; Simon 1973), messy problems (Ackhoff, 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, Gupta et al. 2009). Intermediaries between scientists and policymakers can help bridge this gap (Gieryn 1983, Choi, Pang 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, Buchanan 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 Jr. 2007). Although these studies address the possibility of different roles among experts, empirical support is scarce (Hoppe 2009, Spruijt, Knol et al. 2013, Turnhout, Stuiver 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.

Window 1. Structured search strategy

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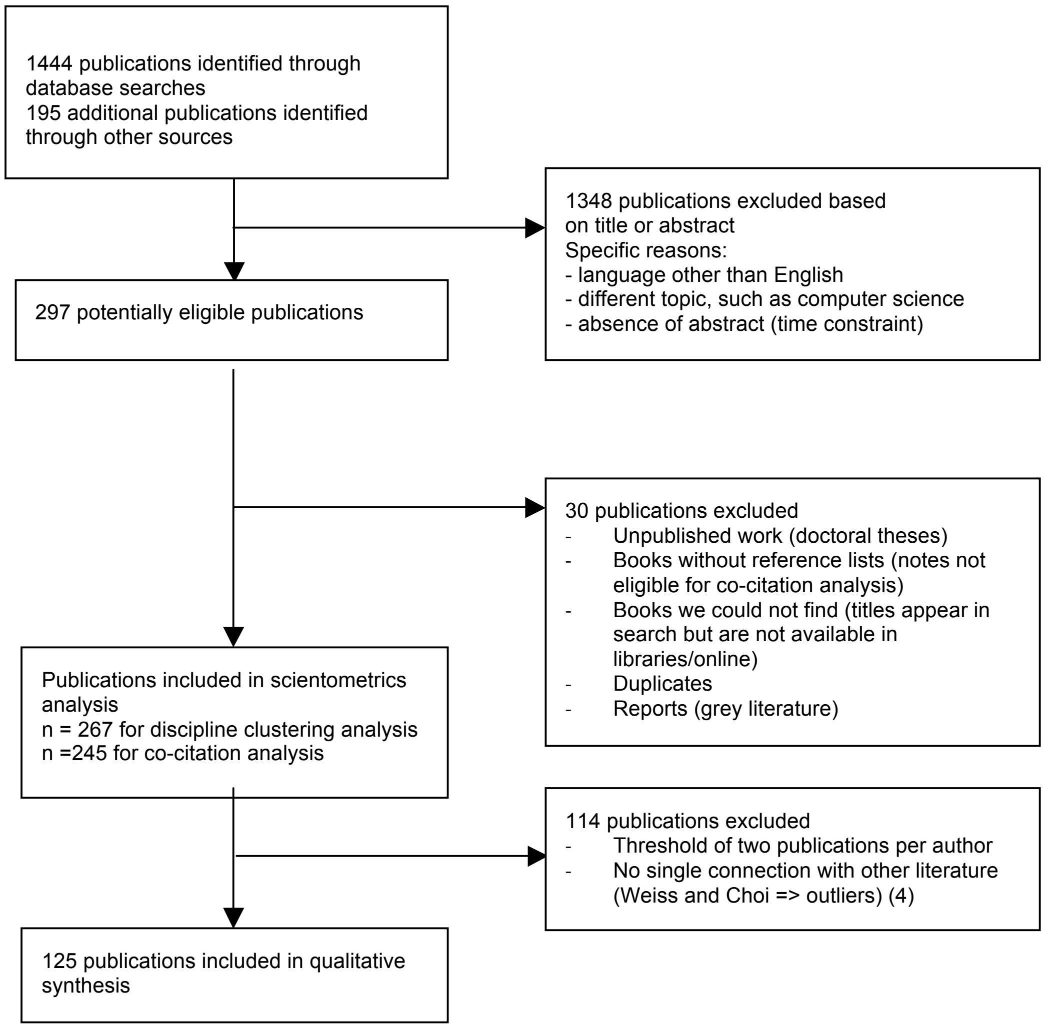
Because some major work appeared to not be published in peer-reviewed journals, we expanded our structured search using the snowball method. This approach required us to read and follow the reference lists of the publications identified in the structured search. After excluding duplicates, we found a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

Figure 1. Flow diagram outlining 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 among different disciplines. We used Leydesdorff's (Leydesdorff, Carley et al. 2013) science overlay map in combination with the Pajek program for this analysis (Nooy, Mrvar et al. 2005, Rafols, Porter 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.

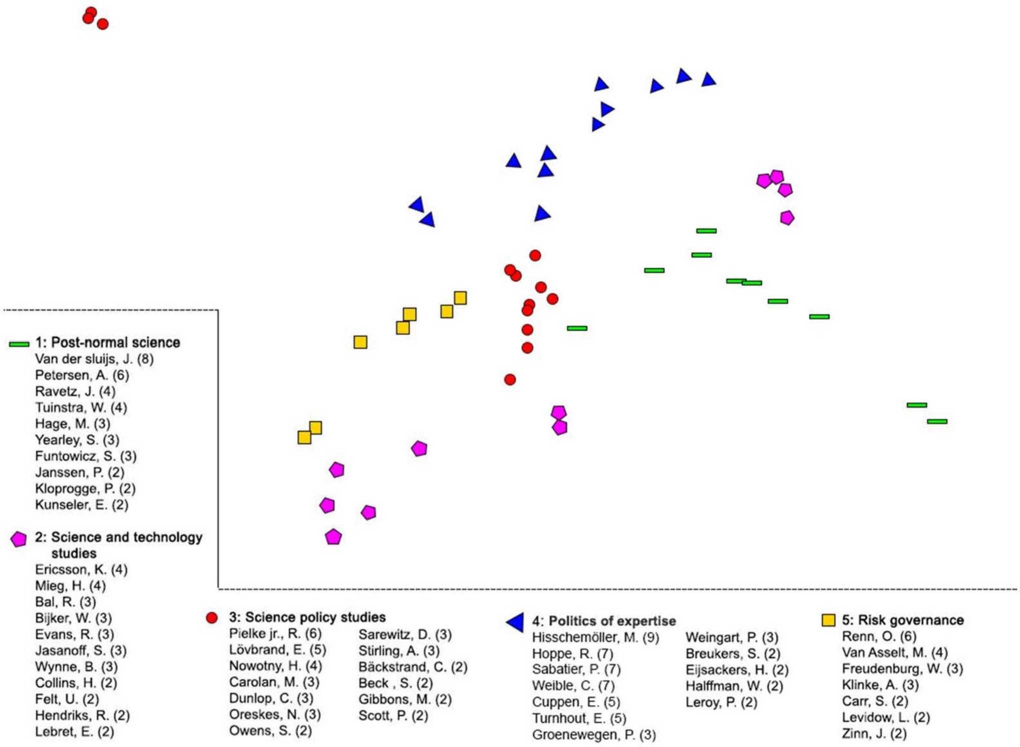
For the discipline analysis, we used all of the selected publications. For the co-citation analysis, we were not able to use all the publications because some had references that we could not import into the analysis program VOSviewer, such as publications in which notes were used instead of reference 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 Figure 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" 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.

Figure 2. Co-citation analysis of cited references



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 1992, Funtowicz 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, Cath 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, Cath 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, Bal 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, Mieg 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, Limoges 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 Figure 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 Jr. 2004, Lövbrand and Öberg 2005, Carolan 2006, Lövbrand 2007, Carolan 2008). Democratizing science should lead to socially robust knowledge (Nowotny 2003, Nowotny 2007). Experts should interact with stakeholders and the public at large to ensure robust decision-making processes (Burgess, Stirling et al. 2007, Stirling 2008, Lövbrand, Pielke et al. 2011). Methods that can facilitate decision processes for contested issues include, for example, stakeholder dialogues, epistemic communities and deliberative mapping (Burgess, Stirling et al. 2007, Stirling, Lobstein 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, Stirling 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, Leroy 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, Sabatier 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, Pattison et al. 2010), that coalition membership is relatively stable over time (Weible, Sabatier 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, Sabatier 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, Weingart 1999, Souren, Poppen 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, Poppen et al. 2007, Hoppe 2009). These differences are subject to change; Van Eijndhoven and Groenewegen found that experts are flexible in their argumentation and able to change viewpoints (Van Eijndhoven and Groenewegen 1991). 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 dialogues. The purpose of a dialogue is to articulate competing perspectives so that stakeholders can learn from each other. Additionally, dialogues 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 dialogue is dependent on the context (Turnhout, Hisschemöller et al. 2007, Turnhout, Hisschemöller et al. 2008).

In conclusion, scientific experts can hold different perspectives when advising on complex issues. Therefore, stakeholder dialogues 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, Carr 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 dialogues); 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 the 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.

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 dialogues)	x	x	x	x	x
Precautionary principle					x
Explicating different points of view within the expert community	x	x	x		

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 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.

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4

Different roles of electromagnetic field experts when giving policy advice: an expert consultation

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ABSTRACT

The overall evidence for adverse health effects of electromagnetic fields (EMF) at levels of exposure normally experienced by the public is generally considered weak. However, whether long-term health effects arise remains uncertain and scientific policy advice is therefore given against a background of uncertainty. Several theories exist about different roles that experts may take when they provide advice on complex issues such as EMF. To provide empirical evidence for these theories, we conducted an expert consultation with as main research question: What are the different roles of EMF experts when they provide policy advice?

Methods: Q methodology was used to empirically test theoretical notions on the existence and determinants of different expert roles and to analyze which roles actually play out in the domain of EMF. Experts were selected based on a structured nominee process. In total 32 international EMF experts participated. Responses were analyzed using Principal Component Analysis and for the open questions we used Atlas.ti.

Results: Four expert roles were found. Most striking differences between the four roles are whether experts consider current EMF policies adequate or not, whether additional –precautionary– measures are needed, and how experts view their position vis-à-vis policymakers and/or other stakeholders.

Conclusion: This empirical study provides support for the so far mainly theoretical debate about the existence of different roles of experts when they give policy advice. The experts' assessment of the degree of uncertainty of the issue turned out to be highly associated with their role. We argue that part of the controversy that exists in the debate regarding scientific policy advice on EMF is about different values and roles.

KEYWORDS

Roles of scientists, Electromagnetic fields, Uncertainty, Policy advice, Expert consultation, Q method.

1. BACKGROUND

The public has been exposed to an increasing number of sources of electromagnetic fields (EMFs) for several decades. In addition to radio and television, these sources also include mobile phones (high-frequency fields) and electrical appliances in the home (low-frequency fields). The exposure associated with the quick proliferation of EMF sources, particularly from mobile phones, DECT phones and WiFi, has raised concerns about the possible adverse health effects.

The overall evidence for the adverse health effects of EMFs at levels of exposure normally experienced by the general public is considered weak [1-3]. Children are thought to be more sensitive to EMF exposure than adults, as their brains are still developing. Studies have shown an increased risk for childhood leukemia associated with low-frequency fields [4]. Thousands of studies have been performed on a wide array of health endpoints. The reviews on the association between EMF exposure and health effects in the general population show either no association or report insufficient and contradictory evidence [5-8]. The International Agency for Research on Cancer (IARC) classified EMFs as category 2B, meaning there is some evidence that EMFs may cause cancer in humans, but at present, the evidence is inconclusive [9,10]. Due to the relatively recent worldwide rise of mobile phone use and rapid introductions of other new technologies, the long-term health effects remain uncertain, and concerns about such effects remain. Therefore, the current policy is given against a background of scientific uncertainty.

In addition to the IARC working group, other international assessments have been conducted to evaluate the potential carcinogenity from exposure to EMFs. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) published information on the potential health risks from exposure to EMFs. The ICNIRP published guidelines for limiting exposure to EMFs (up to 300 GHz) in 1998 and reconfirmed the guidelines in a statement in 2009 [11], stating that no adverse health effects were expected when these guidelines were followed. The BioInitiative, a group of scientists and public health policy professionals, published an overview of what is known about the biological effects that occur when people were exposed to low-intensity EMFs [12]. The report concluded that "a reasonable suspicion of risk exists based on clear evidence of bioeffects at environmentally relevant levels, which, with prolonged exposures may reasonably be presumed to result in health impacts." The BioInitiative experts proposed a precautionary approach, which was stricter than the ICNIRP guidelines. The BioInitiative report was not a systematic review, as opposed to the work of IARC and ICNIRP, and has therefore been criticized for the selective and incomplete use of the literature [13].

Several studies have shown the variation in expert advice and current national policies on EMFs [14,15]. Some countries, such as Switzerland, Denmark and Australia, have adopted a precautionary approach on some EMF issues. Other countries have emphasized the absence of the proof of adverse health effects and have not implemented any policy interventions [16] beyond the existing ICNIRP guidelines.

In this study, we focused on the variance in expert advice. Given that experts usually have access to the same body of knowledge, the question arises how we can understand these differences in advice. When scientific data are inconclusive, experts have to advise in the face of uncertainty because scientific research is not able to provide a complete assessment of the risks or the effectiveness of policy measures. Such uncertainty provides room for a certain degree of subjectivity. Therefore, advice may be affected by normative ambiguity [17] such as personal opinions, values, worldviews and the larger social-cultural context, which could manifest in different attitudes and roles of experts, and subsequently, influence their policy advice.

Previously, we reviewed the theoretical work on the factors that may influence the way scientific experts advise policy makers on complex issues [18], such as EMFs. We found that such policy advice by experts can be investigated from a variety of perspectives, e.g., sociology, environmental studies, and political science. Therefore, the literature that we considered in our review has been published in a variety of journals, covering work from multiple scientific disciplines. The most important factors that were suggested as influencing the role of an expert when giving policy advice were the type of issue (level of uncertainty/complexity); the type of knowledge of the expert; the core values of the expert; the organization in which the expert works; the societal context (i.e., the position of science in society); and the ability of experts to learn and change their viewpoint. The review revealed that although well-elaborated theories exist (e.g., [19,20]), there is limited empirical proof and underpinning.

We conducted an expert consultation using the issue of EMFs to provide more empirical evidence on expert roles and advice. Our goal was to empirically test theoretical notions on the existence of different expert roles and to analyze which roles actually play out in this domain, while exploring some of the factors that are associated with these roles. The following was the main research question: What are the different roles of EMF experts when they provide policy advice? The following sub question was also addressed: Which factors are associated with these different roles? We also explored the effects that different roles may have on policy advice.

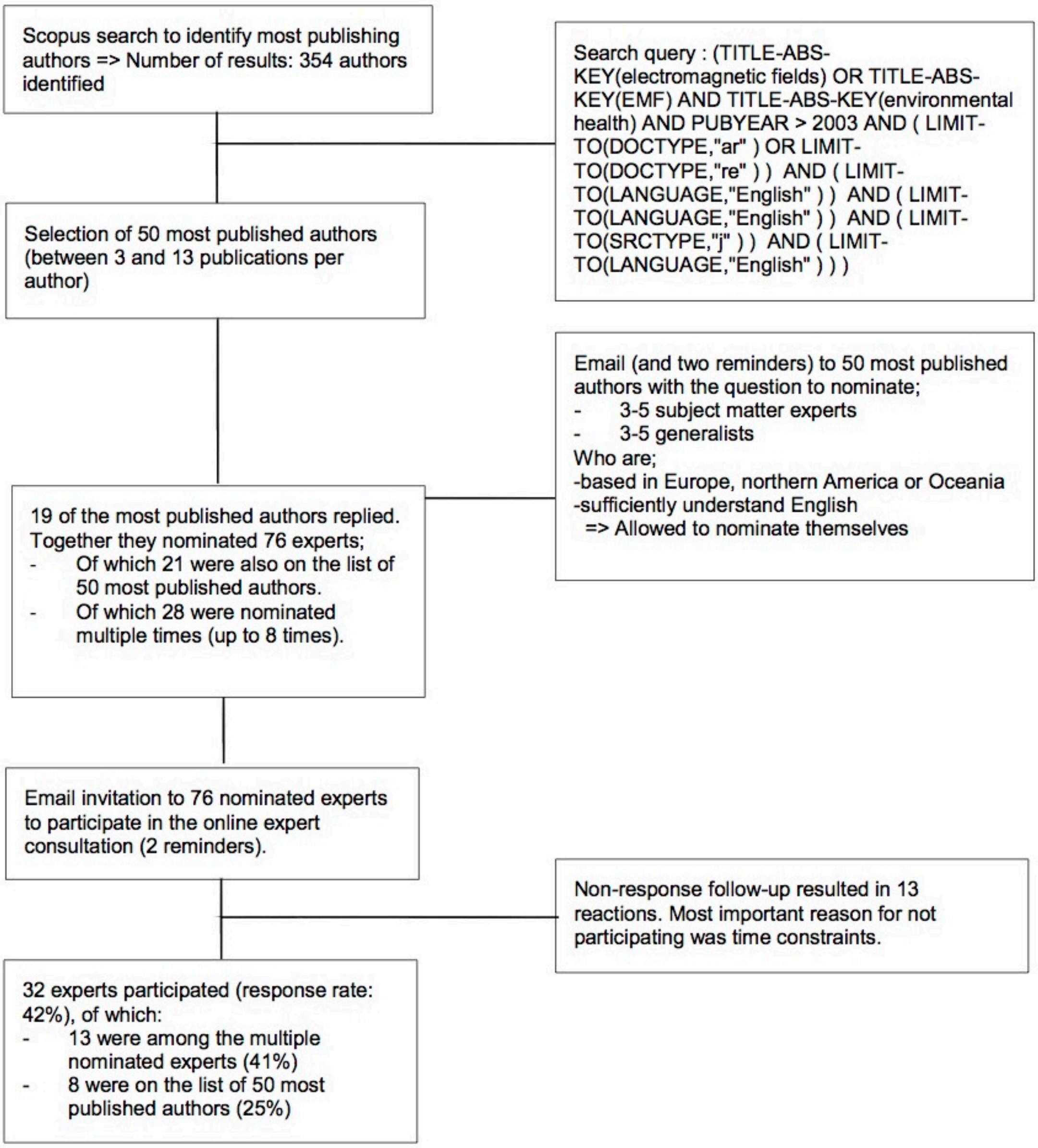
2. METHODS

We selected and approached internationally renowned experts to explore the roles of experts when providing policy advice on EMFs and performed a Q survey to explore their viewpoints. The Q survey involved the formulation of statements (Q sample) about potential roles. Experts were asked to score and rank order these statements in a structured way. Finally, a Q-factor analysis was performed on the expert's scores, and the different roles were interpreted. The sections below further describe the various steps.

Nomination of participants and data collection

We used a structured expert nominee process to obtain a list of prospective experts to take part in the Q survey [21]. Figure 1 shows an overview of the expert nomination and participation process. First, we used the digital search engine Scopus to identify the 50 most published experts (i.e., authors) on EMFs in relation to health issues. We limited the search to the period 2003–2013 to find experts who recently published on the topic. We assumed that these experts were up-to-date on the fields' current scientific state of affairs. We emailed these 50 experts and asked them to nominate 3 to 5 subject matter experts and 3 to 5 generalists. Subject matter experts were fully involved in the scientific debate concerning EMFs and were seen as influential in the domain of EMFs. Generalists were familiar with the scientific debate concerning EMFs and were well-known for giving policy advice. All of the nominated experts were required to be based in Europe, Northern America or Oceania and had to sufficiently understand English. The experts were allowed to nominate themselves. Non-responding experts received two reminders by email. In total, 97 experts were nominated. The nominated experts were asked via email to participate in our online consultation. The online consultation was conducted using POETQ [22], which is a Partnership Online Evaluation Tool with Q methodology. Non-responding experts received two reminders by email. After these reminders, non-respondents received a follow-up email asking them to indicate the most important reason for not participating.

Figure 1. Flow diagram outlining the expert nomination and selection process.



Q methodology

Q methodology was used to explore the different expert roles in the field of EMFs. Q methodology was developed in the 1930s as a technique for studying human subjectivity [23]. This technique involves asking participants to sort a number of subjective statements based on their personal level of agreement/disagreement with the statements. The resulting Q sorts, which represent the viewpoints of individuals, are used to identify clusters of shared ways of thinking that exist among groups of people [24]. These clusters are identified statistically using factor analysis. An important assumption in Q methodology is that a limited number of distinct clusters exist for any particular issue [25]. An extensive description of the history, function and reliability of Q methodology can be found in previous studies [25-28].

Q sample

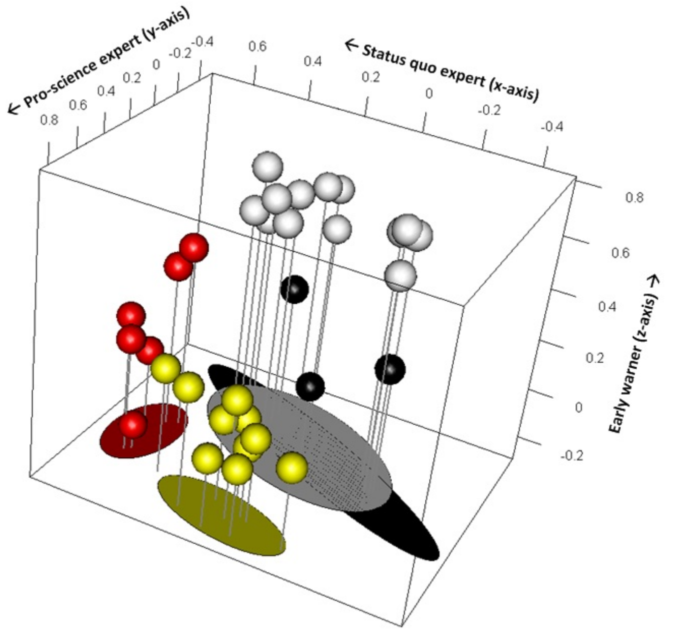
The 38 Q statements were compiled by the authors based on a pilot study [29], on our literature review [18] and on input provided by colleagues working in the domain of EMFs. They included different aspects of the expert roles and advice, including type of issue (level of uncertainty), organization in which the expert works and societal context (position of science in society). Three factors mentioned in the literature review were not incorporated in the Q sample: type of knowledge of the expert (participants were considered to be a relatively homogenous group); core values of the expert (implicitly incorporated in statements; explicit consideration would demand a separate Q sort); and the ability of experts to learn and change their viewpoint (in order to test this, several measurement points would be necessary). The statements were numbered randomly. The balance, clarity and simplicity of the set of statements and the proper functioning of the online data collection program (POETQ) were pre-tested with the help of three respondents who did not take part in the final study.

All of the participating experts rank ordered the 38 statements. First, each statement was categorized into one of three piles: agree, disagree and neutral. Consequently, all statements were rank ordered, pile by pile, over a forced quasi-normal distribution with scores representing the level of agreement, ranging from completely agree (+4) to completely disagree (−4).

Statistical analysis

The PQmethod version 2.33 was used to analyze the correlation and factoring of the Q sorts. A Q sort consisted of the complete rank ordering of the statements as scored by one participant. Using Principal Component Analysis (PCA), a statistical correlation matrix was produced to summarize the similarities in views among participants. Next, clusters of similar viewpoints were identified. Part of the PCA was identifying the highest number of computed factors that hold at least three significantly loading Q sorts. We performed an analysis extracting three, four and five factors to find the most relevant number of factors. A Varimax rotation was applied to optimize the distance between factors. Subsequently, a characteristic Q sort distribution was calculated for each factor based on the standardized factor scores. This distribution revealed the statements that scored similarly within each cluster and therefore gave an idea of the common viewpoints represented by each factor. Next, we analyzed the overall consensus statements to gain an impression of the issues most EMF experts agree on, regardless of the factor they score significantly on. Then, we interpreted the differences between factors based on the so-called distinguishing statements. Given the three factors X, Y and Z, a distinguishing statement for factor X is a statement that received a score in factor X that is significantly different from the corresponding score in factors Y and Z. The authors then labeled each factor. The results of the PCA were visualized using statistical software package R (see Figure 2).

Figure 2. Visualization of participants clustered in four roles: Early warners, 13 experts (white); pro-science, 10 experts (yellow); status quo, 6 experts (red); and issue advocates, 3 experts (black).



The X, Y and Z-axes show the different roles with their factor scores. Note that the axis for the issue advocate is not represented in the figure.

Analysis of open questions; key scientific issue and policy advice

In addition to the Q-sort statements, we asked the experts two open questions. The first question was "What would you call the key scientific issue on EMF at this time?" The second question was "If you were asked to provide policy advice on EMF, what concrete policy measure would you recommend?" The answers were analyzed with the qualitative data analysis program Atlas.ti, version 6.2. This program was used to systematically analyze unstructured data, such as text. The program provides tools to give descriptive codes to primary data material, in this case, the written answers to the two open questions. The descriptive codes were used to structure the data and detect patterns in the respondents' answers.

To detect whether a relationship could be traced between the roles of experts (i.e., the result of the PCA) and the content of their policy advice, we first broadly structured the experts' answers (i.e., policy recommendations in answer to the second open question) in broad categories of policy measures. These categories were derived from three secondary sources: scientific literature, policy documents and conversations with experts. A total of 28 experts gave 34 distinctive policy recommendations. One expert could give several recommendations; thus, the total number of recommendations could exceed the number of respondents. Policy recommendations were analyzed both as one set, as well as distributed over the different factors.

Additional questions

Finally, three additional questions were asked using Likert scales ranging from 1–5 as answer categories. These questions concerned other factors possibly associated with an expert's role, but not yet included in the Q statements. These questions were (1) "I can give my advice independently and uncensored by my corporate hierarchy (independence)"; (2) "My research has had a direct influence on policy choices made (influence)"; and (3) "I think there is a high degree of uncertainty about the health risks posed by EMFs (level of uncertainty)."

3. RESULTS

A total of 32 EMF experts participated in our consultation (see Figure 1). Table 1 shows the selected background variables of the participants, including demographic and employment details. In summary, the average age of the experts was 58 years, 41 percent were female, and 47 percent provided policy advice as their primary task. The majority of the experts were professor/researcher or director of research institutes. Common fields of expertise included epidemiology, public health, toxicology, risk assessment, biology and risk communication.

Table 1. Background variables of the 32 participants

Demographics		
Gender	**Mean Age**	**Nationality**
	(st. dev.)	
59% male	58 *(8.8)*	Italian (5); U.S. (5); French (3); German (3); Swedish (3); Dutch (3); Austrian (2); Swiss (2); Australian (2); British (1); Finnish (1); Greek (1); Hungarian (1)
Employment characteristics		
Field of expertise	**Type of position**	**Type of employer**
Public health; Epidemiology; Risk/exposure/radiation assessment; Policy; Biology (cell/statistics/medical); Toxicology; Risk communication	(Senior) Researcher (11); Professor (10); Head/Director/Manager (7); Advisor (4);	University (13); Research Institute (10); Government (4); NGO (3); Industry (2); Independent Advisory Body (1)

The statistical analysis revealed four factors, i.e., four different sets of distinct statement patterns, which we called roles. In this study, we defined a 'role' as a cluster of distinct viewpoints shared among a group of scientific experts. The results are summarized in Table 2. The four roles indicated in this table illustrate the differences between viewpoints of EMF experts and yield a total explained variance of 56 percent. All 32 experts (i.e., sorts) were considered for the interpretation of the roles. Based on the distinguishing statements and factor scores, we interpreted the four roles and subsequently labeled them as follows: (1) early warners; (2) pro-science experts; (3) status quo experts; and (4) issue advocates. Figure 2 shows a visualization of the experts clustered per role.

Table 2. Summary of main characteristics of the four expert roles

Role	**Key characteristics**	**Statements most strongly agreed with (+3 and +4) and least strongly agreed with (−3 and −4) – see numbers and corresponding statements in Appendix**	**No. of respon-dents *(expl. var.)***	**Summary of typical advice (based on 2nd open question)**
Early warners	Disagreement with current policies. Transparency about methods, assumptions and personal preferences. More research. Precautionary measures.	(+) 18 21 25 26 34 (−) 2 11 22 24 29	13 *(17%)*	Precautionary measures. Develop new more stringent policy standards.
Pro-science	Evidence-based policy. Monitor risks. Not humble about contribution of science to society.	(+) 13 14 15 29 32 (−) 12 23 24 28 35	10 *(17%)*	Evidence-based policy, ALARA and ICNIRP guidelines*
Status quo	Agreement with current policies. No need for additional regulatory measures. Evidence-based policy.	(+) 13 14 20 22 26 (−) 5 6 16 23 28	6 *(11%)*	Evidence-based policy, ALARA and ICNIRP guidelines*
Issue advocates	Interaction with policy makers and stakeholders. More sources than science. No need to explicate differences of opinion between experts.	(+) 2 9 10 14 26 (−) 4 11 12 15 37	3 *(10%)*	*- (advice from 1 expert)*

The following sections describe the four different roles, based on the distinguishing statements. There was one issue that most experts seemed to agree on, namely that when scientific knowledge is inconclusive, policymakers have the task of dealing with the resulting uncertainty (statement 13). Because most experts agreed, this statement does not distinguish between roles, as is shown by the similar factor scores.

Role 1: early warner

The 'early warners' role was shared by 13 experts and explained 18 percent of the total variance. The early warner experts strongly agreed that the risks and uncertainties of EMFs warrant significant investment in additional research (statement 21). They also agreed that when research results were translated into policy advice, experts should be completely open about the methods they use and the assumptions they make (statement 26). According to the early warners, differences of opinion among experts should be made explicit (statement 34). In addition to being open and explicit about differences of opinion, experts should also be transparent about their personal preferences with regard to the policy alternatives and the motivation for these preferences (statement 25).

The early warners *dis*agreed with the current policies on EMFs (statement 29—this is in contrast to the other three roles). In addition to the need for more research and transparency in communication about research, the early warners stated that just monitoring the situation is not enough (statement 22) and that additional precautionary measures are needed to protect public health and the environment (statement 18 and 23). The early warners did not feel tempted to initiate stakeholder cooperation (statement 2), in contrast to the issue advocates.

Role 2: pro-science expert

The 'pro-science expert' role was shared by 10 experts and explained 17 percent of the total variance. The pro-science experts strongly agreed that new policies should be based entirely on the best available scientific knowledge (statement 20). The focus should be on evidence-based policy (statement 5 and 17), and there is no need for scientists to be humble about the possible contribution of science in solving societal problems (statement 32). They felt that experts' personal values should stay separate from their policy advice (statement 24). According to the pro-science experts, the risks and uncertainties of EMFs require monitoring, and there is no need for additional measures, such as precautionary/regulatory measures or significant investment in additional research (statements 21, 22, 23 and 29). The pro-science experts were convinced that their views on the risks of EMFs do not differ very much from those of their colleagues (disagreement with statement 28). Experts holding one of the three other roles also tended to disagree with statement 28, but less strongly.

Role 3: status quo expert

The 'status quo expert' role was shared by 6 experts and explained 11 percent of the total variance. A characteristic of status quo experts was their neutral and satisfied assessment of the current situation regarding EMFs. They strongly agreed with current policies on EMFs (statement 29—note that early warners have an opposite score on this statement) and thought that legislation and regulation is the best way to manage the possible health problems concerning EMFs (statement 4). The status quo experts believed that the risks and uncertainties of EMFs require monitoring, but there is currently no need for additional regulatory measures (statement 22). Furthermore, according to the status quo experts, their role was to address specific questions posed by policymakers (statement 15), and when they advise, they try to keep their personal values separate from the policy advice (statement 24). The status quo experts *dis*agreed with the idea that they should actively approach politicians to present their points of view on EMFs (statement 35). Status quo experts also *dis*agreed with the statement that knowledge of the general public is of less value to policymakers than expert knowledge (statement 17) and gave a neutral score to the statement that new policies should be entirely based on the best available scientific knowledge (statement 20).

The correlation with role 2 was high (0.58). There were two notable divergent viewpoints. First, the status quo experts agreed on the viewpoint that scientists should be humble about the role of science in solving societal problems (statement 32), whereas the pro-science experts *dis*agreed. Second, the status quo experts *dis*agreed on the viewpoint that the knowledge of citizens was of less value to policy makers than expert knowledge (statement 17), whereas the pro-science experts agreed.

Role 4: issue advocate[a]

The 'issue advocate' role was shared by 3 experts and explained 10 percent of the total variance.

A distinct characteristic of the issue advocates was their intensive interaction with policymakers and other stakeholders (statement 12 and 15). The issue advocates tried to use their scientific knowledge to actively direct policy (statement 10), and they were personally motivated to initiate stakeholder cooperation in their research on EMF (statement 2). The issue advocates viewed it as their task to recommend the policy option that they considered best (statement 9). However, they felt that scientific knowledge was not the only source of information to consider when new policies are created (statement 20). According to the issue advocates, it was not necessary to make differences of opinion among experts explicit when they gave policy advice. They also believed that striving for consensus among experts did not best serve policymakers (statement 34 and 37).

Variables associated with the expert roles

All of the experts provided us with information on their perceived independence, perceived influence on policy, perceived key scientific issue regarding EMFs, geographical location and their assessment of the degree of uncertainty about the health risks of EMFs. The first statement, "I can give my advice independently and uncensored by my corporate hierarchy," received an average score of 3.9 on a Likert scale from 1–5 (ranging from disagree to agree), and there were no noticeable differences between the expert roles. Information on whom experts gave advice to and whether advice was given as in individual or representing an employer did not result in noticeable differences between expert roles either. The second statement, "My research has had a direct influence on policy choices made," received an average score of 3.7 without significant differences between the expert roles. The third statement, "I think there is a high degree of uncertainty about the health risks posed by EMFs," received the lowest average score of 2.8, with a marked difference between the expert roles. Namely, the pro-science experts gave an average score of 1.9, and the early warners gave an average score of 3.5. Clearly, the degree of uncertainty about the health risks was perceived differently between these two groups. Geographical location seems to be another influencing factor. The early warners were based in the US, Europe and Australia, whereas the other three expert groups consisted predominantly of Europeans.

The analysis of the answers to the first open question, "What would you call the key scientific issue on EMF at this time?," resulted in one key scientific issue in the field of EMFs: the health effects of exposure to EMFs. This issue was mentioned by 26 of the 32 experts. Some experts specified the possible health effects, e.g., electro hypersensitivity, neurodegenerative diseases, cancer and negative effects on well-being.

Proposed policy advice and expert roles

The analysis of the answers to the second open question, "If you were asked to provide policy advice on EMFs, what concrete policy measure would you recommend?," resulted in a rather clear differentiation of proposed policy advice distributed over the expert roles (see Table 2). The early warners focused on the necessity to develop new standards and implement precautionary measures, such as creating preventive policies for children and informing the public on ways to reduce their exposure. The status quo and pro-science experts both focused on evidence-based policy. They recommended adopting the ALARA principle and the ICNIRP guidelines. The three issue advocates did not propose enough policy measures in our questionnaire. Overall, several experts asked for more research and emphasized the need to communicate to the public about research results. From the Q-sort, we saw that pro-science experts did not agree that a significant investment in research was needed (statement 21), whereas early warners strongly agreed with this statement. Overall, the qualitative analysis of the proposed policy advice confirmed the results of the factor analysis and showed that there was a relationship between an expert's role and the policy advice s/he proposed.

4. CONCLUSION AND DISCUSSION

We conducted an expert consultation using Q methodology on the issue of EMFs to test theoretical notions on the existence of different expert roles and to see what factors were associated with these roles. The main research question was: What are the different roles of EMF experts when they provide policy advice? The following sub question was also addressed: What influences these differences? In addition, we explored the effect that different roles had on possible policy advice. We found four distinct expert roles that were labeled as (1) early warners; (2) pro-science experts; (3) status quo experts; and (4) issue advocates. The early warners disagreed with the current EMF policies. They agreed that more research and precautionary measures were needed and stated the importance of the transparency about methods, assumptions and personal preferences. The pro-science experts agreed that evidence-based policy was legitimate and stated that scientists should not be humble about the contribution of science to society. They preferred to monitor the risks of EMFs. The status quo experts agreed with the current policies on EMFs and saw no need for additional regulatory measures. Finally, Issue advocates agreed that scientists should interact with policymakers and stakeholders. They stated that there was no need to explain the differences of opinion between experts. We found a high correlation (0.58) between roles two and three; the other correlations were 0.35 and lower. The most striking differences between the four roles were whether current policies were adequate or not, whether additional precautionary measures were needed, and how the experts viewed their position vis-à-vis policymakers and/or other stakeholders.

According to the literature [18], the most important factors that influenced the role of an expert when giving policy advice are the following: type of issue (level of uncertainty/complexity); type of knowledge of the expert; core values of the expert; organization in which the expert works; societal context (i.e., the position of science in society); and the ability of the experts to learn and change their viewpoints. A comparison of the results of the literature review with the results of the Likert scale questions and, specifically, statements 18, 21 and 23 of our Q sort showed that the level of uncertainty and the context (i.e., geographical location), seemed to be associated with an expert's role. The reported level of uncertainty differentiated highly between the EMF experts. The early warner experts perceived a much higher level of uncertainty than the pro-science experts. There was variation between the roles on the agreement about the best measures (e.g., more research, precautionary measures). The most notable difference was between the early warners and the pro-science experts. The first group of experts said there was a high level of uncertainty and believed that the risks and uncertainties of EMFs warrant significant investment in research, as well as precautionary measures. The second group of experts reported that there was a low level of uncertainty and believed the contrary viewpoint about more research and precaution. Apparently, a different assessment and interpretation of the level of uncertainty by an expert was associated with their expert role when providing policy advice. Regarding the context, we only asked respondents about their geographical location and at what type of institute they work. More in-depth questions about context (laws, policies in a specific country, party experts work for etc.) would be interesting research questions for a follow-up study. Another point taken from the literature was the suggestion to improve the way in which experts advise on complex issues by democratizing science, e.g., through public participation and stakeholder dialogues [30-35]. In our consultation, we found little support for broadening the advice process. In fact, only the issue advocates seemed to be willing to actively involve the public and other stakeholders in the advisory process (see scores on statements 2, 6, 11 and 17). Public participation is considered important, but our study showed that few experts actually engage in it. Another suggestion to improve the advice was a professional attitude of humility [36,37]. The minimal support for statement 36 that scientists should 'speak truth to power' in their policy advice indicated some degree of humility (see also statement 32).

Furthermore, almost all of the non-Europeans were early warners. The two that were not advised the adoption of the ICNIRP guidelines. This may signify that the European experts in this study showed relatively less need for developing new standards and precaution than their American and Australian colleagues, although this distribution could be coincidental, due to the relatively small sample size. The sample of respondents was the result of a structured expert nomination and selection process. Additional selection criteria, such as the quality of journals that experts published in, could have been applied to the first step of the selection process. Because we were looking for scientists that also provide policy advice we chose to use group knowledge of the experts in order to select our participants instead of investing more time in selecting top scientists. The non-response follow-up research indicated that time constraints constituted the most important reason for not participating. This gave no particular indication of bias, although we cannot exclude the possibility of differences between respondents and non-respondents. One respondent was solely self-nominated. All other respondents were nominated by at least one colleague. An overrepresentation of worried scientists was possible, and this might have depended on funding opportunities. Worried scientists may be more prone to perform and publish research when there are scarce resources, rather than when a research field is well funded.

There is an ongoing debate among researchers about the best analysis strategy when using Q methodology. There are mainly two different ways that are described and advocated: principal component analysis (PCA) in combination with a varimax rotation and centroid analysis in combination with a manual rotation. Both strategies include arbitrary selection criteria, such as the minimum number of respondents loading significantly on a factor. We tested both strategies on our data in a sensitivity analysis. We found a large overlap between the two approaches. Both of the analyses showed three very similar factors, and the fourth factor in the PCA analysis seemed to be split into two separate factors in the centroid analysis. The centroid analysis yielded sorts from 25 experts for the interpretation, whereas the sorts of all 32 experts were included in the PCA analysis. Both of the analyses show substantial similarities in results. Therefore, we decided to use PCA, based on the argument that PCA enabled us to incorporate the highest number of experts in our results.

In the 1980s, Q methodology was mainly applied using face-to-face interviews. More recently, web-based approaches were developed that appeared to perform well [38]. We used the online consultation tool POETQ. Due to our international set of respondents, the geographical distances made it impossible to perform face-to-face interviews. This may have resulted in higher rates among respondents of non-responding, misinterpreting statements or other parts of the consultation and providing less elaborate answers to the open questions. On the other hand, the advantage of using an online tool was that we were able to include more respondents and respondents from geographically separated countries.

We compared our list of respondents to the membership lists of the ICNIRP and the BioInitiative participants. The results pointed towards a relationship between involvement with one of these groups and the attributed expert roles. It was interesting that experts who participated in our consultation thought that their views on the risks of EMFs did not tend to differ from those of colleagues (statement 28). However, the results of our research clearly indicated differences in roles and viewpoints.

Our study confirmed that different distinct roles and viewpoints existed within the community of EMF experts. This research also suggested that the indicated level of uncertainty was one of the factors associated with the EMF experts' roles and, most likely, their policy advice. Further study is needed to determine if this was a causal relation and if this also applies to other environmental health issues. This empirical study provided support for the mainly theoretical debate about the role of experts when they give policy advice. These first empirical findings need corroboration from other empirical studies and on other issues. Additionally, we need to better understand both determinants of roles as well as its effect on policy advice and debate. Based on these results, we argue that part of the controversy that exists in the debate regarding scientific policy advice is about different values and roles (i.e., normative ambiguity [17]). These insights may lead to a better understanding of the processes and differences in the results of scientific policy advice on complex issues.

Endnote

[a]We used a label earlier coined by Pielke Jr [19]. We saw many similarities between Pielke's description of the Issue advocate and ours but noted that the connotation was not exactly the same.

Abbreviations

ALARA, As low as reasonably achievable; DECT, Digital enhanced cordless telecommunications; EMF, Electromagnetic fields; ICNIRP, International commission on non-ionizing radiation protection; IARC, International agency for research on cancer; POETQ, Partnership online evaluation tool with Q methodology; PCA, Principal component analysis

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

PS participated in the design of the study, data collection, analysis and interpretation of the data, and drafted the manuscript. AK participated in the study design, helped with the data collection, analysis and interpretation of the data, and helped to draft the manuscript. AP participated in the design of the study, advised on the data collection and analysis and helped to draft the manuscript. EL participated in the design of the study, advised on the data collection and statistical analysis and helped to draft the manuscript. All authors read and approved the final manuscript.

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5

Differences in views of experts about their role in particulate matter policy advice: empirical evidence from an international expert consultation

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ABSTRACT

There is ample scientific evidence of adverse health effects of air pollution at exposure levels that are common among the general population. Some points of uncertainty remain, however. Several theories exist regarding the various roles that experts may play when they offer policy advice on uncertain issues such as particulate matter (PM). Roles may vary according to e.g. the views of the expert on the science-policy interface or the extent to which s/he involves stakeholders. Empirical underpinning of these theories, however, does not exist. We therefore conducted a consultation with experts on the following research question: What are PM experts' views on their roles when providing policy advice? Q methodology was used to empirically test theoretical notions concerning the existence of differences in views on expert roles. Experts were selected based on a structured nominee process. In total, 31 international PM experts participated. Responses were examined via Principal Component Analysis, and for the open-ended questions, we used Atlas.ti software. Four different expert roles were identified among the participating experts. Main differences were found with respect to views on the need for precautionary measures and on the experts positioning within the science-policy interface. There was consensus on certain issues such as the need for transparency, general *dis*agreement with current policies and general agreement on key scientific issues. This empirical study shows that while most PM experts consider their views on the risks of PM to be in line with those of their colleagues, four distinct expert roles were observed. This provides support for thus far largely theoretical debates on the existence of different roles of experts when they provide policy advice.

KEYWORDS

Scientist roles and viewpoints; Policy advice; Particulate matter; Uncertainty; Expert consultation; Q method.

1. INTRODUCTION

In much of the Western world, the quality of outdoor air has improved in recent decades. Policies on emission reduction in combination with air quality standards for concentrations of various pollutants have lowered overall population exposure to several pollutants. At the same time, evidence of health effects resulting from long-term chronic exposure to air pollution, especially particulate matter (PM), has grown more pronounced (IARC; Raaschou-Nielsen et al., 2013; WHO, 2013, 2014a, 2014b). Further, health effects have been identified at lower exposure levels that fall well below current air quality standards (WHO, 2005). Policies have been implemented to further decrease health impacts of air pollution and have involved the institution of progressively more stringent emission standards for new vehicles (Euro standards), low emission zones in city centers and investments in green technologies such as electric vehicles.

Although there is a consensus on the fact that air pollution is harmful to population health, certain areas of uncertainty remain. Scientific debates on PM mainly concern the specific health impacts of various different particle types and the possible role of gaseous co-pollutants like nitrogen dioxide (Fischer et al., 2015; Valavanidis, Fiotakis, & Vlachogianni, 2008) and physical and chemical properties, underlying causal mechanisms, and the nature of the exposure-response relationship for various health endpoints (Samoli et al., 2005). Differences in hypotheses on which aspects or constituents of PM actually cause health damage have been published on widely. Previous expert elicitations (Cisternas, Bronfman, Jimenez, Cifuentes, & De La Maza, 2014; Cooke et al., 2007; Hoek et al., 2009; Roman et al., 2008; Tuomisto, Wilson, Evans, & Tainio, 2008) have identified uncertainties on the estimated health impacts of PM exposure, and especially for ultrafine particles. These studies also show that experts may differ in their assessments of toxic components of a PM mixture. These differences in interpretations of uncertain scientific evidence may lead to differences in advice on feasible and appropriate policy measures for further reducing risks. However, differences in policy advice not only stem from different viewpoints on content but may also arise from different views on the role of scientific experts in providing policy advice (Davies et al., 2014; Steel, List, Lach, & Shindler, 2004). This is the focus of this study.

The roles of scientific experts may range from deep involvement in policy guidance to an "ivory tower" position. Several papers have theoretically described how experts who provide policy advice cope differently with this role (Pielke Jr., 2007; Weiss, 2003, 2006). Amongst others, Pielke and Weiss published typologies that address four and five roles, respectively, that experts can assume when providing policy advice. Central to their descriptions is the notion that scientists assume different expert roles in different situations. Pielke described the different roles that experts can play when interacting with policymakers in highly uncertain and politicized contexts, presenting his ideas by means of a typology. Pielke identifies four roles: the pure scientist, the science arbiter, the issue advocate and the honest broker of policy alternatives. The *pure scientist* seeks to focus on only facts and does not interact with decision makers. The *science arbiter* answers specific factual questions posed by decision makers. The *issue advocate* seeks to reduce the range of choices available to decision makers by promoting one specific solution. Finally, the *honest broker of policy alternatives* seeks to expand or at least clarify the range of choices available to decision makers. Weiss proposed a typology based on five positions that a scientist can take when addressing uncertainties. Each position represents an attitude that results from a given level of uncertainty in combination with differences in the perceived necessity to take measures and in the willingness to do so based on associated (societal) costs. Some experts may assert that any suggestion of an increase in risk is unacceptable and that the widespread use of new technologies should therefore be permitted only after thorough research has shown no evidence of adverse health effects (John, 2010; Silva & Jenkins-Smith, 2007; Van Asselt & Vos, 2006; Van der Sluijs, 2005). Weiss coined these experts *environmental absolutists*. Other experts view risk as an inextricable part of innovation and accept the possibility of negative (side-) effects in the name of progress. Weiss used the term *scientific absolutists* to refer to these experts. In between these two extremes, Weiss identified the *cautious environmentalist*, the *environmental centrist* and the *technological optimist*.

Existing well-elaborated theoretical work shows that several factors influence an expert's role when s/he gives policy advice. According to a literature review (Spruijt et al., 2014), the most important factors are the following: the type of issue that an expert is advising on (level of uncertainty/complexity); the type of knowledge an expert hold (e.g., education, years of experience, objectivity); an expert's core values (e.g., normative beliefs such as one's view on the desirability of a professional attitude of humility); the organization in which an expert works; the societal context (i.e., the position of science in a certain society to which the policy advise applies); and an expert's ability to learn and change his or her viewpoint. However, there is limited empirical proof and underpinning in support of these theories. An initial pilot study conducted among Dutch experts (Spruijt, Knol, Torenvlied, & Lebret, 2013) suggests that such different expert roles do exist, although not in a way as clearly defined as in the ideal-typical classifications proposed by Pielke and Weiss.

To empirically test theoretical principles on the existence of different expert roles more extensively and analyze which roles play out in the domain of PM, we carried out a consultation with international experts. Our goal is to uncover more empirical evidence on expert roles and advice while exploring factors that are associated with these roles. Our main research question is the following: What are PM experts' views on their roles when providing policy advice? We also explore which patterns can be observed in these experts' views and how they may relate to policy advice.

2. METHODS

To explore PM expert views on their roles as policy advisers, we selected and approached internationally renowned experts and performed a Q-method survey to examine their views. The Q survey first involved the formulation of statements (Q sample) on potential roles. Experts were then asked to score and rank these statements. Finally, a Q-factor analysis was performed on the experts' scores to identify similar response patterns among experts. Clusters of similar patterns were then interpreted. We also performed a qualitative analysis that addresses the open-ended research question on potential effects of expert roles on policy advice. The sections below further describe the method used.

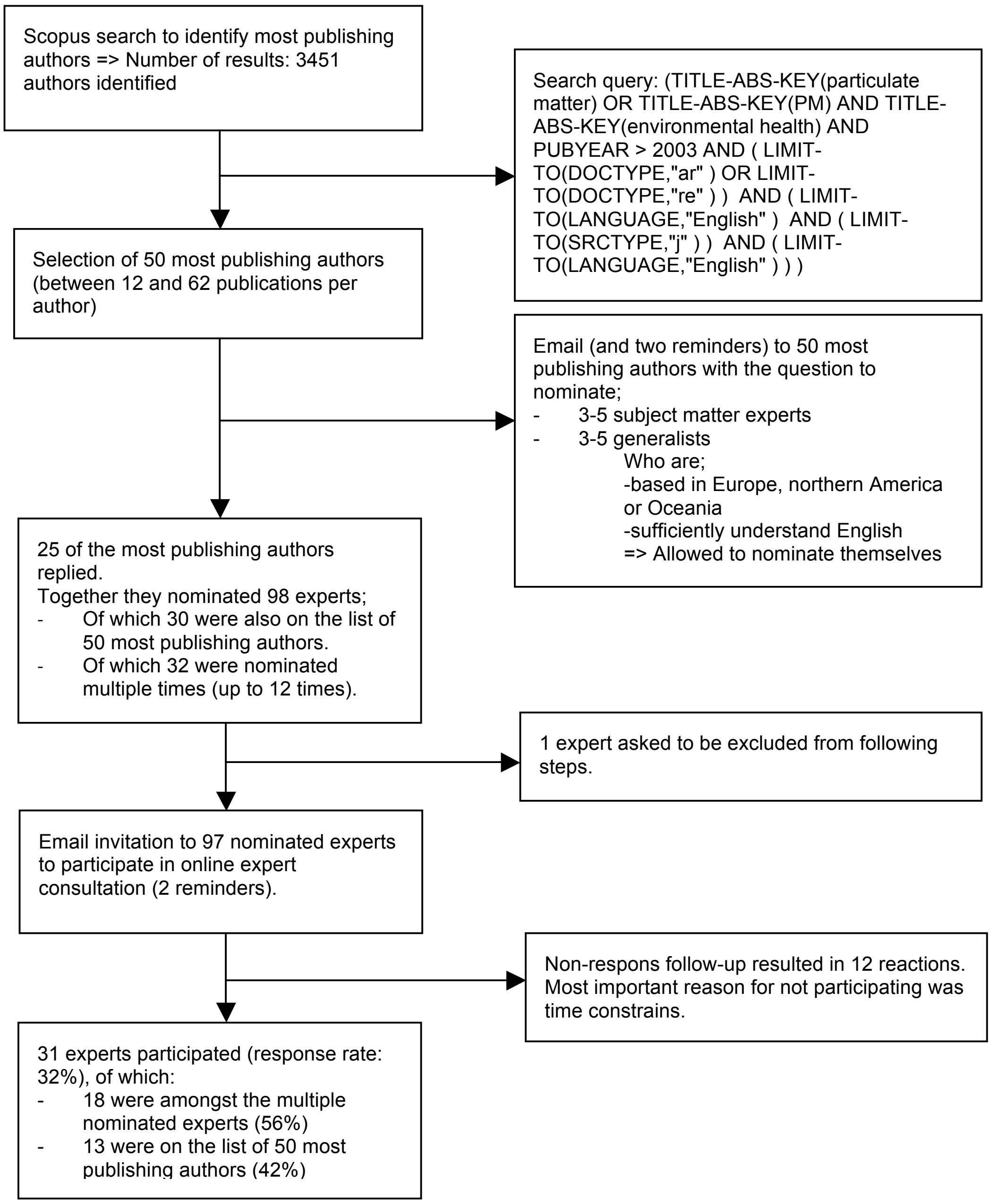
2.1 Nomination of participants

We used a structured expert nominee process to obtain a list of prospective experts to participate in the Q survey (Knol, Slottje, Sluijs, & Lebret, 2010). Figure 1 presents an overview of the expert nomination and participation process. First, we used the Scopus digital search engine to identify the 50 most widely published experts (i.e., authors) on PM in relation to health issues. We limited our search to the 2003-2013 period to find experts who have recently published on the topic; we therefore assume that these experts are aware of the latest findings in this scientific field. Second, we emailed the 50 experts with a request to nominate three to five subject matter specialists and three to five subject matter generalists. Subject matter specialists are fully involved in scientific debates on PM and are considered influential within the domain of PM. Subject matter generalists are familiar with scientific debates on PM and well known for giving policy advice. All of the nominated experts were required to be based in Europe, North America or Oceania and needed to sufficiently understand English. Experts were allowed to nominate themselves. Experts who did not respond received two reminders by email. After these reminders were sent, non-respondents received a non-response follow-up email asking them to indicate their main reason for not participating. In total, 25 experts responded and nominated a total of 98 experts.

2.2 Q methodology

The Q methodology was used to explore the different roles of experts in the field of PM. The Q methodology was developed in the 1930s as a means of studying human subjectivity (Stephenson, 1953). The technique involves asking participants to sort a number of subjective statements based on their personal level of (dis)agreement with each statement. The resulting Q sorts, are the complete statement rankings provided by each participant and represent the individual views of the respondents. These are used to identify clusters of shared ways of thinking that exist among groups of people (Steelman, 1999). These clusters are identified statistically via factor analysis. An important assumption of the Q methodology is that a limited number of distinct clusters exist for any particular issue (Brown, 1980). For an extensive description of the history, function and reliability of the Q methodology, see (Brown, 1993; Nicholas, 2011; Thomas, 1992).

Figure 1. Flow diagram outlining the expert nomination and selection process



2.3 Q sample

Thirty-eight Q statements (see Table 1) were compiled by the authors based on typologies presented by Pielke and Weiss (Spruijt et al., 2013), a literature review (Spruijt et al., 2014) and inputs provided by colleagues working within the domain of PM. The statements focused on different aspects of expert roles and advice, including types of issues (level of uncertainty) and societal contexts (position of science in society). Two factors identified in the literature review were not incorporated in the Q sample: type of expert knowledge (participants were considered a relatively homogenous group—see also Table 2 with background variables on the participants, including their fields of expertise) and expert abilities to learn and change their views (to test this, several measurement moments would be necessary). The experts' core values were implicitly incorporated into the statements; explicit consideration would demand a separate Q sort. The statements were numbered randomly. The balance, clarity and simplicity of the set of were pre-tested with the help of three respondents who did not take part in the final study.

2.4 Data collection

From the 98 nominated experts, 97 were contacted by email with a request to participate in our online consultation (one expert asked to be excluded from following research phases). The online consultation was conducted using POETQ software (Jeffares, Dickinson, & Hughes, 2012). POETQ is a Partnership Online Evaluation Tool that employs the Q methodology. The 31 participating experts rank ordered the 38 statements. Each statement first needed to be categorized in one of three groups: agree, disagree and neutral. Subsequently, all statements were rank ordered within each group over a forced quasi-normal distribution with scores representing the level of agreement and ranging from completely agree (+4) to completely disagree (-4)—see Figure 2 for an example of a score sheet used for the ranking of each statement.

In addition to ranking the Q-sort statements, the experts were presented with two open-ended questions. The first question posed was: "What would you call the key scientific issue on PM at this time?" The second question posed was: "if you were asked to provide policy advice on PM, what concrete policy measure would you recommend?" Furthermore, background variables were collected on experts educational background, job description, current employer(s) (university, research institute, government, NGO etc.), gender, year of birth and experience with giving policy advice. Finally, three additional questions were asked using Likert scales ranging from one to five. These questions concerned other factors that may be associated with an expert's role, but which were not included in the Q statements. Namely, (1) I can give my advice independently and uncensored by my corporate hierarchy (independence), (2) my research has had a direct influence on policy choices made (influence), and (3) I think there is a high degree of uncertainty about the health risks posed by PM (level of uncertainty).

Table 1. Statements with factor Q sort values

No	Statement	Role 1:	Role 2:	Role 3:	Role 4:
1	As an expert, I think I should cooperate with stakeholders in assessing the health risks of PM.	**-1***	1	2	2
2	I feel personally motivated to initiate stakeholder cooperation in my research on PM.	-1	0	-1	1
3	I expect the government to coordinate the governance process on PM.	1	0	-1	1
4	I think that possible health problems concerning PM are best managed by legislation and regulation.	**4**	0	0	**-2**
5	In my opinion, public health and environmental problems related to PM are too complex for only evidence-based policy.	-4	-4	-1	-2
6	As an expert, I should take the perspectives of the general public into account in my research.	-1	-1	-1	**-3**
7	As an expert, it is my duty to maintain continuous dialogue with policymakers.	**-2**	**3**	0	0
8	As an expert, it is my responsibility to inform policymakers about all possible policy options and their potential consequences.	0	1	**-2**	**3**
9	As an expert, it is my task to recommend the policy option that I consider best.	3	1	**-3**	1
10	I try to use my scientific knowledge to actively direct policy.	0	0	-1	-1
11	In my opinion, science should be limited to systematic knowledge production.	-2	**-3**	-2	**0**
12	I think there should be strict separation between scientists who do research and policymakers who build policy on that research.	-2	-4	-3	**-1**
13	When scientific knowledge is inconclusive, I think policymakers have the task of dealing with the resulting uncertainty.	2	0	3	1
14	I think that scientific research should contribute to solving societal problems.	1	2	4	4
15	My only involvement in politics is to address specific questions posed by policymakers.	-1	-1	0	-1
16	I think that public anxiety is a good motivation for policy action, even when there is no scientific explanation for the anxiety.	-3	-1	-1	-4
17	In my opinion, knowledge of the general public is of less value to policymakers than expert knowledge.	0	-1	**-2**	0
18	If the health and environmental impacts of a project involving PMs were highly uncertain, I would advise precautionary measures to protect public health and the environment.	2	3	1	0
19	I expect future technological innovations to reduce the negative effects of PM on health and the environment.	1	2	1	1
20	I think new policies on PM should be based entirely on the best available scientific knowledge.	0	**4**	**-2**	1
21	I believe the risks and uncertainties of PM warrant significant investment in additional research.	2	0	2	1
22	I believe the risks and uncertainties of PM require monitoring but there is currently no need for additional regulatory measures.	-4	-3	-4	**-1**
23	I believe the risks and uncertainties of PM warrant significant investment in precautionary measures	**4**	1	0	**-4**
24	In addition to scientific knowledge, I preferably incorporate my personal values in my policy advice.	-3	**-1**	-3	-3
25	I think policy makers are best supported when experts are transparent about their personal preferences with regard to the policy alternatives and the motivation for these preferences.	1	2	**0**	**3**
26	In giving policy advice, I think experts should be completely open about the methods they use and assumptions they make.	3	4	4	4
27	I think I should inform policy makers about the science underlying my policy advice.	1	3	3	3
28	My views on the risks of PM tend to differ from those of my colleagues.	-3	-3	-4	**0**

29	I agree with current policies on PM.	-2	-1	-1-	-2
30	I am very interested in the political debate surrounding my research.	0	**2**	0	-1
31	I think the primary task of a scientist is to publish in peer-reviewed scientific journals.	**0**	-2	**3**	-3
32	I think scientists should be humble about the role of science in solving societal problems.	-1	**-2**	**1**	-1
33	I think that scientific output should be assessed by an extended peer community of all who are affected by the issue.	-1	0	**2**	0
34	I think that differences of opinion among experts should be made explicit when giving policy advice.	2	1	2	2
35	Just as NGOs and industry do, I think scientists should actively approach politicians to present their points of view on PM.	0	1	0	0
36	I think scientists should 'speak truth to power' in their policy advice.	1	0	0	2
37	I think policy makers are best served when experts strive for consensus in their policy advice.	0	-2	1	-2
38	I primarily work in science because I like the intellectual challenge.	3	**-2**	1	2

* Numbers in bold are distinguishing statements.

2.5 Statistical analysis

The PQmethod version 2.33 program was used to analyze the correlation and factoring of the Q sorts. Via Principal Component Analysis (PCA), a statistical correlation matrix was used to summarize Q sort similarities, i.e., views among participants. Next, clusters of Q sorts were identified. The PCA identified the highest number of computed factors that hold at least three significantly loading Q sorts. To find the most relevant number of factors, we performed an analysis that involved extracting three, four and five factors. To optimize the distance between factors, varimax rotation was employed. Subsequently, a characteristic Q sort distribution was calculated for each factor based on the standardized factor scores. This distribution reveals the statements that are scored similarly within each factor and therefore summarizes common viewpoints represented by each factor. We then examined the overall consensus statements to obtain an impression of issues that most PM experts agree on regardless of the factors they score significantly on. We then interpreted differences between the factors based on the so-called distinguishing statements. Based on three factors (X, Y and Z), a distinguishing statement for factor X is a statement with a score in factor X that is significantly different from the corresponding score of factors Y and Z. We then labeled each factor. The PCA results were visualized using the R statistical software package (see Figure 3).

2.6 Analysis of open-ended questions; key scientific issues and policy advice

Answers to the open-ended questions were analyzed with using the Atlas.ti version 6.2 qualitative data analysis program. This program can be used to systematically analyze unstructured data such as text. The program provides tools for assigning descriptive codes (e.g., "developing emission standards" and "implementing technical measures") to primary data material, and in this case written answers to two open-ended questions. The descriptive codes were used to structure the data and to detect patterns in the respondents' answers.

To detect whether a relationship could be traced between expert roles (i.e., the PCA results) and the content of their policy advice, we first broadly grouped the experts' answers in broad categories of policy measures. These categories were derived from three secondary sources: scientific literature, policy documents and conversations with experts. In total, 28 experts gave 60 distinct policy recommendations. One expert could give several recommendations, which explains why the total number of recommendations exceeds the number of respondents. Policy recommendations were analyzed both as one set and as distributed over the different factors.

3. RESULTS

In total, 31 PM experts participated in our consultation (see Figure 1). The sample consisted of several multiply nominated experts, thus resulting in a selection of world leading experts on the issue. Table 1 summarizes the responses as Q sort values for the four factors distinguished in the factor analysis (see section 3.1). Table 2 shows selected background variables on the participants, including those concerning demographics and employment details. In summary, the average age of the experts was 59 years, 84 percent were male and 26 percent occupied roles that primary involved providing policy advice. Most of the experts were professors/researchers or directors of research institutes. Common fields of expertise included epidemiology, public health, air pollution/quality, risk/exposure assessment, aerosol science and medicine.

3.1 PCA; four expert roles

The PCA revealed four factors (see Figure 3 for a visualization). These factors show differences between the views of groups of PM experts and yield a total explained variance of 61 percent. Following the selection and analysis criteria, 23 experts (i.e., sorts) were included for the factor interpretation. In Table 1 the statements are sorted for each factor into the range -4 to +4, i.e. the factor Q sort values. The sorting is based on rank orderings of the factor Z-scores. Based on the distinguishing statements and factor scores, we interpreted all factors and subsequently labeled them: (1) regulatory advocates, (2) engaged scientists, (3) humble scientists and (4) noninterventionists. In the following sections, we will refer to these factors as 'roles' (see Figure 3 for a visualization of participants clustered across the four roles and Table 3 for a summary of the four roles). Table 3 presents the explained variance and statements with highest (dis)agreement broken down by the four roles.

3.1.1 Role 1: regulatory advocate

The *regulatory advocates'* role was shared by eight experts and explained 22 percent of the total variance. These experts strongly agree that possible health problems concerning PM are best managed through legislation and regulation. More specifically, they believe that risks and uncertainties associated with PM warrant significant investment in precautionary measures. They disagree that public anxiety serves as a good motivation for policy action. These experts do not agree they should cooperate with stakeholders in assessing the health risks of PM, and they do not see it as their duty to maintain continuous dialogue with policymakers. Finally, they strongly disagree with the statement that PM issues are too complex to be addressed with evidence-based policy measures. This latter viewpoint is widely shared with the *engaged scientist*s (role 2). In summary, regulatory advocates strongly agree that possible health problems related to PM are best managed through legislation and regulation.

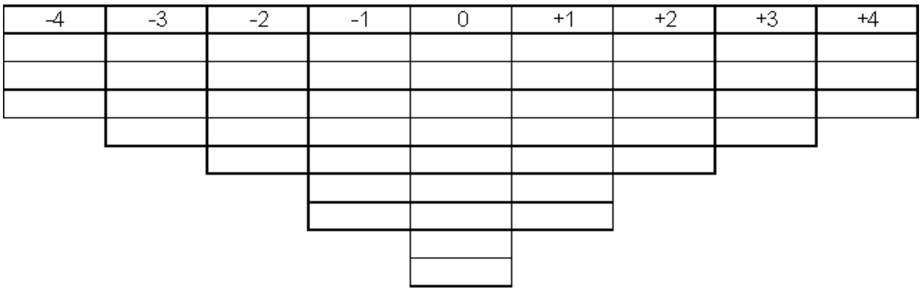
3.1.2 Role 2: engaged scientist

The *engaged scientists'* role was shared by seven experts and explained 16 percent of the total variance. Like the regulatory advocate, these experts strongly disagree with the notion that PM is too complex to be addressed through evidence-based policy measures. They think new policies should be based entirely on the best available scientific knowledge. Engaged scientists disagree that science should be limited to the generation of systematic knowledge. Indeed, they strongly disagree with the statement that there should be strict separation between scientists who conduct research and policymakers who build policies on that research. Furthermore, the engaged scientists agree that it is their duty to maintain continuous dialogue with policymakers, and they are very interested in political debates surrounding their research. Engaged scientists are the only scientists examined who disagree with the statement that they primarily work in the scientific realm because they enjoy the intellectual challenge. Finally, of the four categories of scientists, engaged scientists most strongly *dis*agree that scientists should remain humble regarding the role of science in solving societal problems. In summary, engaged scientists see no strict separation between science and policy and agree that new policies should be evidence-based.

Table 2. Background variables of participants

Demographics		
Gender	Mean Age *(st. dev.)*	Nationality
84% male	59 *(10,6)*	U.S. (12); German(3);Swiss(3); Greek(3);Dutch(2);Canadian(2); Italian(2);Spanish(2); Polish(1);British(1)
Employment characteristics		
Field of expertise	Type of position	Type of employer
Epidemiology; public health; air pollution/quality; risk/exposure assessment; aerosol science; medicine	Professor(14); head/director(8); researcher/lecturer(7);scientific officer(2); retired(1)	University(16);government(8); research institute(6);NGO(1)

Figure 2. Example of score sheet for the rank ordering of all statements (forced quasi normal distribution).



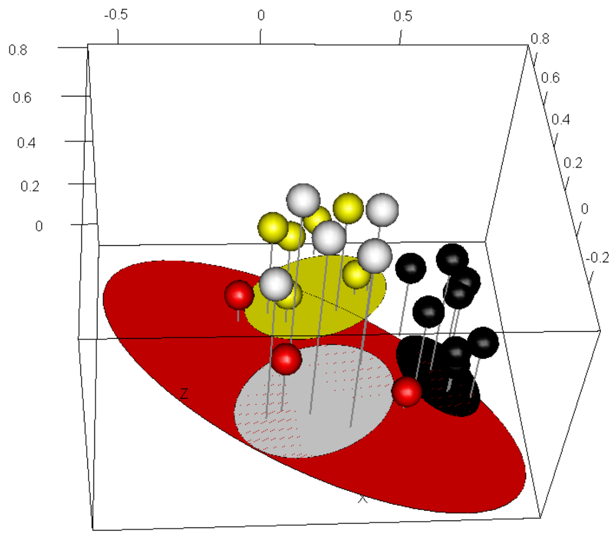
3.1.3 Role 3: humble scientist

The *humble scientist* role was shared by five experts and explained 14 percent of the total variance. These experts strongly agree that scientific research should contribute to the solving of societal problems. However, they are the only experts who modestly agree that scientists should remain humble regarding the role of science in solving societal problems. The other three groups of scientists disagree slightly with this statement.

Humble scientists *dis*agree that new policies on PM should be based entirely on the best available scientific knowledge, and they also disagree with the statement that knowledge of the general public is of less value to policymakers than expert knowledge. These experts disagree that it is their responsibility to inform policymakers of all possible policy options and of their potential consequences, and they also disagree that it is their task to recommend the policy options that they consider to be the best. Both of these views stand in contrast with those the other three groups of scientists. Instead, they feel that a scientist's main role is to publish in peer-reviewed scientific journals. They also agree that scientific output should be assessed by an extended peer community of all who are affected by the issue. Although experts who assume one of the other three roles agree that policymakers are best supported when experts are transparent about their personal preferences with regards to policy alternatives and about their motivations for these preferences, the *humble scientists* ranked this statement as neutral. In summary, humble scientists believe that they should publish in peer-reviewed journals and that experts should remain humble on the contributions of science to society.

Figure 3. Visualization of participants clustered in four roles

Regulatory advocate, 8 experts; engaged scientist, 7 experts; humble scientist, 5 experts; and noninterventionist, 3 experts.



The X, Y and Z-axes show the different roles with their factor scores. Note that the axis for the *noninterventionists* is not represented in the figure.

Table 3. Summary of main characteristics of the four expert roles.

Role	Key characteristics	Statements most strongly agreed with (+3 and +4) and least strongly agreed with (-3 and -4) – see numbers and corresponding statements in Table X	No. of respon-dents *(expl. var.)*
1 **Regulatory advocate**	Manage possible health problems by regulation and legislation; Invest in precautionary measures; No stakeholder cooperation; Evidence-based policy.	(+) 4 9 23 26 38 (-) 5 16 22 24 28	8 *(22%)*
2 **Engaged expert**	Evidence-based policy; No strict separation between science and policy; Dialogue between experts and policymakers; Scientists should *not* be humble.	(+) 7 18 20 26 27 (-) 5 11 12 22 28	7 *(16%)*
3 **Humble scientist**	Scientists should be humble and publish in peer-reviewed journals. Knowledge of the general public is also important. Policy should not be based entirely on scientific knowledge.	(+) 13 14 26 27 31 (-) 9 12 22 24 28	5 *(14%)*
4 **Noninterventionist**	Disagreement with managing possible health problems by regulation and legislation; Do not invest in precautionary measures; Experts should be transparent about personal preferences.	(+) 8 14 25 26 27 (-) 6 16 23 24 31	3 *(9%)*

3.1.4 Role 4: noninterventionist

The *noninterventionist's* role was shared by three experts and explained nine percent of the total variance. This role includes the lowest number of experts, and these experts received relatively few nominations (see Figure 1 and 3). Noninterventionists score neutral on the statement "my views tend to differ from those of my colleagues", whilst the other three roles disagreed with this statement. In addition, they most strongly agree that policymakers are best supported when experts are transparent about their personal preferences with regards to policy alternatives and their motivation behind these preferences. In comparison with the other three roles, the *noninterventionists dis*agree with the statement that possible health problems concerning PM are best managed through legislation and regulation and that investments in precautionary measures are needed. Moreover, they assume a moderate position on the believe that there is currently no need for additional regulatory measures to address risks and uncertainties associated with PM—the other three roles strongly disagree with this statement, meaning that they believe that more measures are required. Furthermore, experts should not take views of the general public into account in relation to their research. In summary, noninterventionists think they hold different views than their colleagues and disagree that more measures are needed to manage the possible health consequences of PM.

3.2 Experts not captured in the four roles

Eight experts were not attributed to one of the four roles described above. These experts loaded strong either on more than one of the roles or on none in particular. Six of the eight experts loaded strong on role 1 in combination with relatively high loadings on one or more other roles. Note that these experts are not included in Figure 3.

3.3 Views shared among experts

The PCA revealed nine consensus statements that experts share agreement on. These are statements that therefore do not distinguish experts. Differences between scores on consensus statements do not exceed two points (on a scale from -4 to +4). Four topics are addressed in the nine consensus statements, namely (1) agreement with the need to be *transparent* on differences of opinion among experts and on research methods used and the science underlying policy advice given (statements 26, 27 and 34), (2) disagreement with *current policies* on PM (statement 29), (3) some agreement with the expectation that *technological innovations* will mitigate negative effects of PM on public health and on the environment (statement 19) and (4) some agreement on the notion that risks and uncertainties associated with PM warrant significant investment in *additional research* (statement 21).

3.4 Likert scale variables

All of the experts provided us with information on their perceived independence, perceived influence on policy, and on their assessments on degrees of uncertainty concerning PM health risks. The first statement "I can give my advice independently and uncensored by my corporate hierarchy" received an average expert score of 4.6 (st.dev. 0.90) on a Likert scale ranging from one to five (ranging from disagree to agree). The second statement "My research has had a direct influence on policy choices made" received an average score of 4.2 (st.dev. 0.70). The third statement "I think there are high degrees of uncertainty surrounding health risks posed by PM" received an average score of 1.8 (st.dev. 0.72). No clear-cut differences were found between the expert roles. Given the small number of respondents, no testing on statistical differences was performed.

3.5 Main scientific issue

An analysis of answers to the first open-ended question "What would you call the key scientific issue on PM at this time?" revealed one key scientific issue in the field of PM: health effects of different PM compositions. This issue was mentioned by 27 of the 31 experts, indicating a high level of consensus. Very few other issues were mentioned, including: the effects of traffic related policies on health, drafting new standards, and defining socially acceptable levels of risk. Issues cited did not differ across the four expert roles.

3.6 Proposed policy advice

The second open-ended question was the following: "If you were asked to provide policy advice on PM, what concrete policy measure would you recommend?" Twenty-six experts provided policy advice. Note that the question was very open-ended, and the fact that some experts did not present certain recommendations does not imply that they necessarily disagree with those recommendations.

In general, the experts tended to agree on several factors. On a policy level, existing norms and limit values were considered a matter of concern. Roughly two thirds of all of the experts indicated that either existing limit values should be tightened and/or that additional limit values for e.g., soot or ultrafine particles should be put into place. In addition, better enforcement of existing legislation was mentioned by some. A successful measure mentioned pertained to existing EU regulation on emission standards for vehicles.

For the specific purpose of lowering air pollution levels, strategies that involved curbing emissions at the source were mentioned most often, most specifically diesel emission reduction. In addition, reducing wood burning and the banning of coal plants and old industrial operations were mentioned. Roughly one third of all of the experts recommended policy measures that change behaviors, e.g., promoting active lifestyles by for instance promoting the use of bicycles and public transport. Other specific policy measures mentioned include low emission zones, polluter pays principle enforcement and increased monitoring (multi-pollutant monitoring sites in particular). Finally, certain experts noted that investing in research is still necessary, and especially in relation to the health risks of different PM components. No link/association was identified between the expert roles and the allocation of advice given.

4. CONCLUSIONS AND DISCUSSIONS

We conducted an international expert consultation on PM policy advice using the Q methodology. Our goal was to empirically test theoretical principles on the existence of different expert roles and to analyze which roles actually play out in this domain. We also explored some factors that are associated with these roles. The main research question explored was the following: What are PM experts' views on their roles when providing policy advice? We also explored which factors are associated with the different roles identified and the effects that different expert roles may have on policy advice.

We identified four different expert roles, which are referred to as the regulatory advocate, engaged scientist, humble scientist and noninterventionist (see Table 3). Regulatory advocates strongly agree that possible health problems relating to PM are best managed through legislation and regulation. Engaged scientists see no strict separation between science and policy and agree that new policies should be evidence-based. Humble scientists think that they are required to publish in peer-reviewed journals and that experts should remain humble regarding the contributions of science to society. Finally, noninterventionists think that they hold different views from their colleagues (whilst the other three roles disagreed with statement 28 meaning that they do not think they hold different views from their colleagues) and disagree that more measures are needed to manage possible health problems associated with PM. Among experts working in the realm of PM, main differences in viewpoints concern whether risks and uncertainties associated with PM warrant significant investments in precautionary measures, whether scientists are primarily required to publish in peer-reviewed scientific journals, whether possible health problems concerning PM are best managed through legislation and regulation and whether it is an expert's responsibility to recommend policy options that s/he considers most suitable. Furthermore, broad consensus was found on the key scientific issue (i.e., health effects of different PM compositions); on disagreement with current policies (although possibly for various reasons; other and more policies are needed vs. there are too many policies); and on the need to be transparent about differences of opinion held among experts, on research methods used and on the science underlying policy advice given.

As pointed out by many authors the process of doing research as well as advising policy makers based on that research is not purely objective and value free (Doubleday & Wilsdon, 2012; Owens, Rayner, & Bina, 2004; Stirling, 2010). Our study indicates that experts hold different views about their role in giving policy advice, even when they have access to the same scientific research results. Based on our earlier literature review, suggestions to improve ways in which experts (should) advise on complex issues include: democratizing science (i.e., public participation and stakeholder dialogs), transparency in methods and assumptions, professional attitude of humility and making different points of view within the expert community explicit (Spruijt et al., 2014). All these suggestions underline the relativity of expert knowledge and acknowledge the normative elements and political nature of science advice.

The results of a pilot study (Spruijt et al., 2013) and PM expert roles identified in this Q method study show that the two roles that represent the highest degree of explained variance and the largest number of experts show similarities. The first role in both studies emphasizes the need to take more –precautionary- measures to reduce PM emissions. The second role in both studies focuses on the belief that the realms of science and policy should not be separated. Compared to the results of an international consultation with electromagnetic field (EMF) experts that we conducted using a similar methodology (Spruijt, Knol, Petersen, & Lebret, 2015), we see more consensus within the PM expert group than within the EMF expert group. For example, higher levels of consensus were found in terms of Likert scale scores, policy advice given, the experts that load on multiple factors, and in terms of the homogeneity of expert nominations. This may be a consequence of the longer history of debates and research activities in the domain of PM; the research field is more mature. Background variables reveal a homogenous group of PM experts for a longer period of time. This may increase possibilities of "group think" (i.e., within a certain stable group, individuals begin thinking similarly and may be less receptive to ideas that do not match their own viewpoints). Nonetheless, we identified four different expert roles through our consultation. Differences between the PM expert roles appear less significant than across the EMF expert roles: more PM experts held significant loadings on multiple factors than the EMF experts. Again, this denotes a greater degree of consensus in the PM expert group.

Our consultations add empirical data to the existing theoretical work. Pielke and Weiss published typologies that address four and five roles, respectively, that experts can assume when providing policy advice. Central to their descriptions is the notion that scientists assume different expert roles in different situations. In our study we combined statements that refer to elements of both typologies and also from notions from our earlier literature review. For instance from Mode 2 science and post-normal science about e.g. experts' attitude towards public participation, transparency, and views on a professional attitude of humility. The combined 38 statements, therefore, span broader dimensions than encapsulated by the two typologies from Pielke and Weiss. This prevents a direct comparison between the observed four factors and the theoretical typologies. Nonetheless several commonalities are easily recognized, notably experts' views on the level of interaction between experts and policy makers as well as views on appropriate ways of dealing with the complex issues (regulation, precaution, monitoring).

Methodological considerations and limitations

Two analysis strategies are commonly used when applying the Q methodology: principal component analysis (PCA) in combination with varimax rotation and centroid analysis in combination with manual rotation. Both strategies involve the use of somewhat arbitrary selection criteria (e.g., the minimum number of respondents that should load on a factor in order for this factor to be considered significant). As a sensitivity analysis, we applied both strategies on our data. The PCA resulted in four factors which included sorts from 23 experts. The centroid analysis showed three factors that included sorts of 22 experts. Respectively eight and nine experts who loaded on multiple or on none of the factors were not categorized into any of the four roles and were therefore excluded from the factor interpretation. We interpret these excluded experts as another indication that there is consensus among PM experts; their viewpoints are not mutually exclusive (Collins & Evans, 2007). Overall, the sensitivity analysis shows that patterns found in our data are similar between the PCA and centroid analysis results. More specific, 17 experts were attributed to the same factor in both the PCA and centroid analysis meaning that roles 1, 2 and 3 are rather stable. If we would have labelled the three centroid analysis factors they would probably have received similar labels as the PCA factors we presented. Expert elicitations are often for practical reasons limited to certain geographic areas. When using the online Q method tool, distance no longer stands as an obstacle (unless face-to-face interaction is required). We surveyed a set of individuals from countries that are far apart geographically. Although we did invite individuals from Oceania to take part, none participated. We restricted the study to a survey of English-speaking experts, which in itself generated lower probabilities of participation from several countries. The first nomination phase may also have omitted experts who are not part of the community that publishes in scientific journals. Still, the sample used was larger than those used in most previous elicitations (Cooke et al., 2007; Hoek et al., 2009; Roman et al., 2008; WHO, 2013). The results of this study cannot be extrapolated to Asia, Latin America and/or Africa. These continents face different challenges regarding air pollution, and experts may carry different views on their roles as policy adviser.

In our study, we focused on the opinions of experts about their role in providing policy advice. We did not assert whether such advice actually has had an influence on policies. On average, the score on the statement "My research has had a direct influence on policy choices made" was 4.2 (5-point Likert scale), indicating that experts belief they do influence policy. A wide body of literature is devoted to the role and relativity of science in policy making, e.g. (Owens et al., 2004; Upham & Dendler, 2015). Assessing the actual influence of science advice on policy was beyond the scope of our study and would altogether require different approaches.

Disagreements between the experts participating in our study generally relate more to the process of policy advising and to the relationship between science and policy (the need for dialogue with policy makers, stakeholder interaction, etc.) than to underlying science. This constitutes a difference from EMF experts, who also disagree on the extent to which EMF affects public health.

In conclusion, experts in the field of PM appear to agree that, based on scientific research, more policies should be imposed to reduce health impacts of air pollution. Compared to experts in other environmental health fields, PM experts share a broad consensus on key scientific issues and on proposed policy measures. Nonetheless, PM experts carry varying views on their roles as science advisers. The most important differences related to their views on appropriate levels of interaction with policymakers and other stakeholders and to their preferred attitudes (humble or not).

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6

Expert views on their role as policy adviser; empirical data from case studies on electromagnetic fields, particulate matter and antimicrobial resistance

ABSTRACT

Background and aims: Scientific experts differ in the way they provide policy advice on complex and uncertain risk issues such as the health effects of electromagnetic fields, particulate matter and antimicrobial resistance. Whereas some experts believe that their primary task is to conduct fundamental research, others actively engage in policy dialogues and/or advocate specific policy measures. Although the literature provides theoretical, ideal-typical ideas about expert roles, there is little empirical underpinning for these ideas. Our aim was to gather empirical data and evidence regarding these different roles by eliciting experts' views on their role as policy adviser.

Methods: An international study was conducted among experts on three complex and uncertain environmental health issues: electromagnetic fields (EMF), particulate matter (PM), and antimicrobial resistance (AMR). Q methodology was used to explore different expert roles. Data were collected online among internationally recognized experts selected through a structured expert nominee approach. In total, 32 EMF experts, 31 PM experts, and 28 AMR experts participated. Each expert evaluated and ranked 38 statements describing different aspects of how they see their role as policy advisers. Responses were analyzed using factor analysis.

Results: The results indicated that experts indeed differ in the way they view their own role in the policy dialogues surrounding EMF, PM and AMR. Six factors were discerned, with marked differences between the three issues. Expert views on their role as policy adviser were most strongly dependent on the issue of concern. Experts differed in their views on the need for precaution and their motivation to initiate cooperation with stakeholders for policy advice. There was general agreement about the need to be transparent about both research methods and assumptions made when giving policy advice. There was general disagreement on the idea that science and policy should be strictly separated. Additionally, most experts thought that their views on the risks of EMF/PM/AMR did not differ from those of their colleagues. Great dissensus was found among views on the best ways to manage the risks and uncertainties of EMF/PM/AMR (monitoring, additional regulatory measures, precautionary measures).

Conclusions: The empirical data demonstrate the existence of different expert views on the role of experts as policy advisers. These views are somewhat field-specific. The theoretical ideal-typical roles from the literature can indeed be identified to a certain extent.

KEYWORDS

Expert roles, policy advice, uncertainty, electromagnetic fields, particulate matter, antimicrobial resistance, Q methodology.

1. INTRODUCTION

Scientific knowledge, particularly the position of scientific experts, is publicly contested, especially when the topic under debate is surrounded by uncertainty (Lentsch & Weingart, 2011; OECD, 2015; WRR, 2008). Topics exemplifying this uncertainty are electromagnetic fields, antibiotic resistance and particulate matter. Sometimes, debates are covered heavily by the media, as seen in the cases of IPCC Climategate and the L'Aquila earthquake, potentially leading to public distrust of science. When this occurs, expert advice may lose its legitimacy (Martini and Boumans 2014). Several scholars have discussed the various potential roles of experts in the interplay between science and policy. Wildavsky's (Wildavsky, 1979) famous phrase, "speaking truth to power," suggests a clear division of labor between science and politics. According to Wildavsky, scientific experts should communicate objective and true knowledge to politicians. Jasanoff (Jasanoff, 1990), however, states that "the notion that scientific advisers can or do limit themselves to addressing purely scientific issues seems fundamentally misconceived" because the idea of the completely impartial, value-free scientist is outdated and the relationship between science and policy is intricate. These competing positions point to the dilemmas that scientists often face in their interactions with policymakers, as well as to the tension between science and policymaking in general (McNie, 2007). Discussions about the position of scientific experts in the policy process are especially likely to occur when knowledge is incomplete, the research subject is characterized by uncertainty, and values are ambiguous. These properties characterize many modern environmental health risks, which are complex problems embedded in wider environmental, social, economic and political systems (Beck, 1992; Briggs, 2008; Klinke & Renn, 2006; Renn & Graham, 2005; Sarewitz, 2004; Van Asselt, 2010; Van Asselt & Renn, 2011). The WHO defines environmental health risks as "all the physical, chemical, and biological factors external to a person, and all the related factors impacting behaviours. It encompasses the assessment and control of those environmental factors that can potentially affect health" (WHO, 2012).

In many cases, the effects of environmental health hazards may be determined to be irreversible before conclusive scientific evidence becomes available. This requires policymakers to make decisions even when the available data are scarce, uncertain and contradictory (Van der Sluijs, 2010; Wardekker, Van der Sluijs, Janssen, Kloprogge, & Petersen, 2008). Hence, there may be pressure on scientific experts to give policy advice even under conditions of substantial scientific uncertainty and ambiguity of values. Our research interest lies in the roles of scientific experts and the tension that results from the combination of uncertain knowledge with society's demand for clear policy advice. In the present paper, we examine the ways in which scientific experts cope with this tension, with an empirical focus on the topics of electromagnetic fields (EMF), particulate matter (PM) and antimicrobial resistance (AMR). These cases were chosen because they are all complex environmental health issues surrounded by scientific uncertainty, but they differ in the level/type of uncertainty that affects them, the societal unrest they cause, and the current policy processes addressing them. These three topics entail disparate risks. The list of complex issues that we could have studied is longer and subject to change. Other issues worthy of study are, for example, nanotechnology, endocrine disrupters and climate change.

The debate over EMF focuses on whether a causal relationship exists between exposure and adverse health effects at the exposure levels experienced by the general population. Reviews of the association between EMF exposure and health effects in the general population either show no association or report insufficient and contradictory evidence. Although long-term health effects remain uncertain, concerns in the general population about such effects persist. The policy process currently addressing EMF relies on regulatory science and is directed at monitoring, compliance, and debating ways to cope with the general public's worries about possible health effects. The notion of regulatory science can be generally described as the sciences targeted at addressing the challenges of regulatory and policy processes (Weinberg 1972, Jasanoff 1990).

The debate regarding PM mainly concerns the health impacts of different particle types, the underlying causal mechanisms of these health impacts, and the nature of the exposure-response relationship for various health endpoints. The quality of outdoor air has improved in recent decades in much of the western world. Concurrently, the evidence of health effects resulting from long-term chronic exposure to air pollution at levels currently experienced by the general population has grown more compelling. Research efforts on PM can be described as regulatory science: the focus is on identification of the most toxic constituents, monitoring, compliance, and approaches to cost-effective emission reductions from various sources to reduce exposure and the health effects associated with exposure.

The debate over AMR focuses primarily on the question of how to cope with the global threat of emerging antibiotic resistance. What are the transmission routes and potential impacts of resistant bacteria on human health? Given such uncertainty, which policy measures can be taken and what is the proportionality of the possible measures? Current measures aiming to counter AMR follow the paradigm of human medicine: i.e., infection prevention, screening, treatment and isolation of infected hospital patients. Future measures may be stricter, which would raise ethical questions: e.g., can we isolate individual patients for months using the argument that such a strategy would benefit public health? The policy process currently addressing AMR is different from the EMF and PM processes. There is no regulatory science because medical doctors (i.e., experts) are also making professional policies. In many cases, these policies are made on the national level, and adjusted and implemented at the institutional level, i.e., in hospitals and other healthcare facilities.

The debates involved in all three issues raise the question of how experts address requests to provide policy advice under conditions of scientific uncertainty. Linked to all these debates is the question of whether (precautionary) measures should be taken and if so, what these measures should consist of. Theoretical approaches to these questions exist, but empirical foundations are limited (Spruijt et al., 2014). To add data and insight to the small existing empirical knowledge base, we undertook three case studies with the following as our main research questions: How do experts view their roles when providing policy advice on EMF/PM/AMR? and What are the main similarities and differences between experts' views of their roles in the fields of EMF, PM and AMR?

2. METHODS

To explore expert views on their roles as policy advisers, we selected and approached internationally renowned experts and performed a Q-method survey (more information on this method is provided below). The Q survey first involved the formulation of statements (Q sample) on various aspects of potential expert roles. Experts were then asked to score and rank these statements. Finally, a Q-factor analysis was performed on the experts' scores to identify similar response patterns among experts. Clusters of similar patterns were then interpreted by the authors. We also performed a qualitative analysis to address two open-ended research questions. The sections below further describe the methods used.

2.1 Nomination of participants

We used a structured expert nominee process to obtain a list of prospective experts to participate in the Q survey (Knol, Slottje, Sluijs, & Lebret, 2010). First, we used the Scopus digital search engine to identify the 50 most widely published experts (i.e., authors) in each field in relation to health issues. We limited our search to the period 2003-2013 to identify experts who have recently published on the topic; we therefore assume that these experts are aware of the latest findings in their respective scientific fields. Second, we emailed the 150 experts with a request that they nominate three to five subject matter experts and three to five generalists. Subject matter experts were defined as fully involved in scientific debates on EMF/PM/AMR and are considered influential within their domains. Generalists were defined as familiar with scientific, policy and societal debates on EMF/PM/AMR.

2.2 Q methodology

The Q methodology was used to explore the different roles of experts in the fields of EMF/PM/AMR. This methodology was developed in the 1930s as a means of studying human subjectivity (Stephenson, 1953). The technique involves asking participants to sort a number of subjective statements based on their personal levels of (dis)agreement with each statement. The resulting Q sorts, which represent individual views, are used to identify clusters of shared ways of thinking that exist among groups of people (Steelman, 1999). These clusters are identified statistically via factor analysis. An important assumption of the Q methodology is that a limited number of distinct clusters exist for any particular issue (Brown, 1980). For an extensive description of the history, function and reliability of the Q methodology, see (Brown, 1993; Nicholas, 2011; Thomas, 1992).

2.3 Q sample

Thirty-eight Q statements (see Appendix) were compiled by the authors based on typologies presented by Pielke and Weiss (Weiss 2003, Pielke Jr. 2007, Spruijt, Knol et al. 2013), a literature review (Spruijt et al., 2014) and inputs provided by colleagues working within the domains of EMF, PM and AMR. The statements focused on different aspects of expert roles and advice, including type of issue (level of uncertainty), need for policy measures, transparency, and societal contexts (position of science in society). The statements were numbered randomly. The balance, clarity and simplicity of the set of statements were pre-tested with the help of seven respondents who did not take part in the final study.

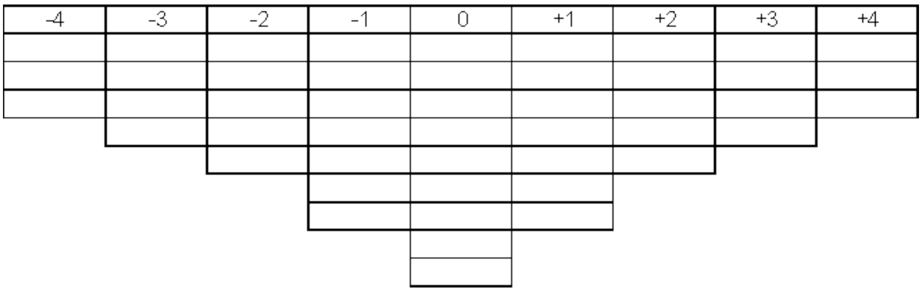
2.4 Data collection

From the 304 nominated experts, 303 were contacted by email with a request to participate in our online consultation (one expert asked to be excluded from subsequent research phases). The online consultation was conducted using POETQ software (Jeffares, Dickinson, & Hughes, 2012). POETQ is a Partnership Online Evaluation Tool that employs the Q methodology. All participating experts rank ordered the 38 statements. Each statement first needed to be categorized into one of three groups: agree, disagree and neutral. Subsequently, all statements were rank ordered within each group over a forced quasi-normal distribution, with scores representing the level of agreement and ranging from completely agree (+4) to completely disagree (-4); see Figure 1 for an example of a score sheet used for the ranking of each statement.

In addition to ranking the Q-sort statements, the experts were presented with two open-ended questions: “What would you call the key scientific issue on EMF/PM/AMR at this time?” and “If you were asked to provide policy advice on EMF/PM/AMR, what concrete policy measure would you recommend?” Furthermore, background variables were collected on the experts’ educational backgrounds; job descriptions; current employer(s) (university, research institute, government, NGO etc.; gender;

year of birth; and experience giving policy advice. Finally, three additional questions were asked using Likert scales ranging from one to five (from disagree to agree). These questions concerned other factors that may be associated with an expert's role but that were not included in the Q statements. The statements were: (1) I can give my advice independently and uncensored by my corporate hierarchy (independence); (2) my research has had a direct influence on policy choices (influence); and (3) I think there is a high degree of uncertainty about the health risks posed by EMF/PM/AMR (level of uncertainty).

Figure 1. Example of score sheet used for the ranking of statements



2.5 Statistical analysis

The PQmethod version 2.33 program was used to analyze the correlation and factoring of the Q sorts. A Q sort includes the complete statement ranking provided by each participant. Using Principal Component Analysis (PCA), a statistical correlation matrix was used to summarize Q sort similarities, i.e., similar views among participants. Next, clusters of Q sorts were identified. The PCA identified the highest number of computed factors (i.e., expert roles) that hold at least three significantly loading Q sorts (i.e., participants). To find the most relevant number of factors, we performed an analysis that involved extracting five, six or seven factors. To optimize the distance between factors, varimax rotation was employed. Subsequently, a characteristic Q sort distribution was calculated for each factor based on the standardized factor scores. This distribution reveals the statements that are scored similarly within each factor and therefore summarizes common viewpoints represented by each factor. We interpreted differences between the factors based on the so-called distinguishing statements. Based on three factors (X, Y and Z), a distinguishing statement for factor X is a statement with a score in factor X that is significantly different from the corresponding score of factors Y and Z. We interpreted and labeled each factor, i.e., expert role. Where possible, we used the same labels as in our earlier publications on EMF and PM (Spruijt, Knol et al. 2015, Spruijt, Knol et al. 2016).

3. RESULTS

In total, 92 experts participated in the consultation: EMF (32), PM (31) and AMR (29). The nomination process was identical for all three groups. The nominated experts differed by case. The percentage of participating experts that were multiply nominated was, in ascending order, 28% (AMR), 41% (EMF) and 58% (PM). The maximum multiple nominations were 6 (AMR), 8 (EMF) and 12 (PM). These numbers indicate the level of consensus that exists in a field regarding who its top experts are. In these three groups, approximately 30 top international experts had multiple nominations (see Table 1).

Table 1. Nomination of participants in numbers

	AMR	EMF	PM
Number of nominators	25	19	25
Number of nominated experts	132	76	98
Number of nominations	182	138	208
Number of multiply nominated experts	31	28	32
% participating multiply nominated experts	28%	41%	58%

Table 2 shows background variables on the percentage of female experts: 7% (AMR), 41% (EMF) and 16% (PM); the average of the entire group is 21 percent. The mean age of the experts is 51 (AMR), 58 (EMF) and 59 (PM) years; the average of the entire group is 56 years. Giving policy advice is the primary task of almost half of the participating AMR and EMF experts, and of a quarter of the PM experts. The most common fields of expertise partially overlap: all three groups include epidemiologists and public health experts.

Table 2. Background variables

	Gender	*Age*	*Policy advice*	*Field of expertise*
	Female	Mean	Primary task	
AMR	7%	51	46%	epidemiology; public health; (veterinary) medicine; microbiology; infectious disease
EMF	41%	58	47%	epidemiology; public health; toxicology; risk assessment; biology; risk communication
PM	16%	59	26%	epidemiology; public health; medicine; air pollution/quality; risk/exposure assessment; aerosol science
Total	*21%*	*56*	*40%*	

3.1 Six factors

The principal component analysis resulted in six factors. We interpreted the factors and subsequently labeled them as: (1) engaged scientist, (2) pro-science expert, (3) regulatory advocate, (4) humble scientist, (5) transparent expert and (6) issue advocate. Table 3 shows the distribution of experts over the six factors based on their fields of expertise. Table 4 shows a summary of the main characteristics of the six factors. The Appendix shows the Q sort values for each statement by factor. The first three factors are dominated by experts from one field. The first factor is predominantly composed of AMR experts, the second factor is predominantly composed of EMF experts, and the third factor mainly consists of PM experts. Factors 4, 5 and 6 are a combination of experts from all three fields of expertise.

Table 3. Number of experts and explained variance by field

Factor	EMF	PM	AMR	Sub total	Explained variance
1	1	4	9	14	14
2	12	1	-	13	9
3	1	8	1	10	12
4	2	3	2	7	9
5	3	1	2	6	9
6	3	1	1	5	6
≠ factor*	10	13	15	37	
Total	32	31	29	92	59

* ≠ factor' indicates the number of experts that did not load on any factor

Factor 1 was shared by 14 experts and explained 14 percent of the total variance. Mostly AMR (9) and PM (4) experts load on this factor. Experts associated with this factor have a strong tendency to maintain continuous dialogue with policymakers. In contrast with the other five roles, these experts disagree with the statement "When scientific knowledge is inconclusive, I think policymakers have the task of dealing with the resulting uncertainty". Moreover, this group agreed that experts should not be humble about the role of science in solving societal problems. The experts strongly agree that new policies should be based on the best available scientific knowledge and they strongly disagree that it is the primary task of scientists to publish in peer-reviewed journals. In summary, these experts highly value scientific knowledge in solving societal problems and stress the importance of a continuous dialogue between scientists and policymakers.

Factor 2: Pro-science Expert

Factor 2 was shared by 13 experts and explained 9 percent of the total variance. Out of these 13 experts, 12 were EMF experts. These experts strongly agreed that new policies should be based entirely on the best available scientific knowledge. Moreover, they tended to agree that science should be limited to systematic knowledge production and that they primarily work in science because of the intellectual challenge. However, they did not think that it is an expert's task to recommend the policy option that s/he considers best. Furthermore, they agreed that the knowledge possessed by the general public is of less value to policymakers than expert knowledge and *dis*agree that experts should take into account the perspective of the general public in their research. According to these experts, the risks and uncertainties of EMF/PM require monitoring, and there is no need for additional measures (such as precautionary/regulatory measures or significant investment in additional research). In summary, these experts strongly agreed that new policies should be based on scientific knowledge, that the knowledge possessed by the general public is less valuable than that of experts and that monitoring is the most suitable way to address the risks and uncertainties of EMF.

Factor 3: Regulatory Advocate

Factor 3 was shared by 10 experts and explained 12 percent of the total variance. Out of these 10 experts, 8 were PM experts. These experts strongly agreed that possible health problems concerning mainly (in this case) PM are best managed through legislation and regulation. They strongly disagree that monitoring is enough and believe that significant investment in additional research is necessary. The 10 experts agree that it is the primary task of scientists to publish in peer-reviewed journals and they expect future technological innovations to reduce negative effects on health and the environment. These experts do not agree that they should cooperate with stakeholders, and they do not see it as their duty to maintain continuous dialogue with policymakers. In summary, these experts strongly agree that possible health problems are best managed through legislation and regulation, that a scientist's primary task is to publish in peer-reviewed journals and that they do not have a responsibility to maintain continuous dialogue with policymakers.

Factor 4: Humble Scientist

Factor 4 was shared by 7 experts and explained 9 percent of the total variance. These experts are from all domains: EMF (2), PM (3) and, AMR (2). These experts strongly agree that scientists should be humble about the role of science in solving societal problems and that scientific output should be assessed by an extended peer community of people affected by the issue. They disagree with the statement that experts should recommend the policy option that they consider best and slightly disagree that experts need to be transparent about their personal preferences and motivations with regard to policy alternatives. These experts do think that health problems are best managed by legislation and regulation; they are neutral on the statement that public health and environmental problems related to EMF/PM/AMR are too complex for only evidence-based policy. In summary, these experts strongly agree that scientists should be humble about the role of science in solving societal problems and have moderate scores on most other statements.

Factor 5: Transparent Expert

Factor 5 was shared by 6 experts and explained 9 percent of the total variance. These experts are from all domains: EMF (3), PM (1) and, AMR (2). These experts strongly agree that they should be completely open about the methods they use and assumptions they make when giving policy advice. In addition, they agree that experts should inform policymakers about the science underlying their policy advice. Finally, they also strongly agree that differences of opinion among experts should be made explicit when giving policy advice. Although they slightly agree that public health and environmental problems related to EMF/PM/AMR are too complex for only evidence-based policy, they agree that new policies should be based entirely on the best available *scientific* knowledge. There is no need for scientists to actively approach politicians, and they do not expect the government to coordinate the governance process on EMF/PM/AMR. They disagree that health risks and problems are best managed by legislation and regulation (in contrast to factor 3, the regulatory advocates) and do not expect future technological innovations to reduce the negative effects of EMF/PM/AMR on health and the environment. In summary, these experts emphasize the importance of the following: transparency about research methods and assumptions, explicating differences of opinion among experts and informing policymakers about the science underlying policy advice.

Factor 6: Issue Advocate

Factor 6 was shared by 5 experts and explained 6 percent of the total variance. These experts are from all domains: EMF (3), PM (1) and, AMR (1). The issue advocates try to use their scientific knowledge to actively direct policy and view it as their task to recommend the policy option that they consider best. Issue advocates do not believe in a strict separation between scientists, who conduct research, and policymakers, who build policy on that research (all other factors show disagreement with this statement as well, but the issue advocates disagree most strongly). They are the only group that is highly interested in political debates surrounding their research. Furthermore, they disagree that an expert's only involvement in politics is to address specific questions posed by policymakers. According to the issue advocates, it is not necessary to make differences of opinion among experts explicit when providing policy advice. Issue advocates are neutral in regard to policy decisions. They disagree that significant investment in precautionary measures or additional research is needed. They are neutral about the need to monitor risks and uncertainties and other additional measures. They are also neutral about the statement that public anxiety is a good motivation for policy action, whereas all others disagree with this. In summary, these experts focus on actively interacting with policymakers and politics and are fairly neutral in regard to the policy measures that should be implemented.

Table 4. Summary of main characteristics of the six expert roles.

Factor/ Role	Key characteristics	Statements most strongly agreed with (+3 and +4) and least strongly agreed with (-3 and -4) – see numbers and corresponding statements in Appendix	No. of respon-dents *(explained variance)*
Engaged scientist	Evidence-based policy; Dialogue between experts and policymakers; Scientists should *not* be humble.	(+) 7 8 19 20 21 (-) 11 12 22 29 31	14 *(14%)*
Pro-science expert	Evidence-based policy. Working in science is an intellectual challenge; Knowledge possessed by the general public is less valuable; Monitor risks, no need for additional measures.	(+) 14 20 22 26 27 (-) 5 6 16 23 28	13 *(9%)*
Regulatory advocate	Manage possible health problems by regulation and legislation, including precaution; Invest in additional research; No continuous dialogue with policymakers; Evidence-based policy.	(+) 4 23 26 31 38 (-) 5 16 22 24 28	10 *(12%)*
Humble scientist	Scientists should be humble; Assessment of scientific output by extended peer community; Manage possible health problems by regulation and legislation.	(+) 11 12 19 21 32 (-) 13 14 22 24 28	7 *(9%)*
Transparen t expert	Experts should be transparent about methods and assumptions; Differences of opinion among experts should be made explicit; Evidence-based policy.	(+) 21 25 26 34 38 (-) 4 11 19 24 29	6 *(9%)*
Issue advocate	No strict separation between scientists and policymakers; Evidence-based policy; Actively direct policy, recommend best option; No need to invest in precaution or research.	(+) 2 9 10 14 30 (-) 11 12 15 23 37	5 *(6%)*

3.2 Consensus statements

A couple of statements were identified as consensus statements, meaning there were no significant differences between the rankings of these statements by the different expert roles (i.e., factors). The first consensus statement was "I think I should inform policymakers about the science underlying my policy advice," with an average score of +2. The second consensus statement was "I think scientists should speak 'truth to power' in their policy advice," with an average score of +1. The moderate score on this last statement suggests that the “old” idea of scientists speaking truth to power is not widely supported by respondents. This moderate view corresponds with recent publications addressing views on the science-policy interface where scientists and policymakers are interlinked.

3.3 Scores per statement before factor analyses

As the factor analysis excluded 37 experts from the factor interpretation, we also analyzed the raw data to obtain an impression of scores from all experts. We present four categories: statements with the strongest agreement, statements with the strongest disagreement, statements with the most far-reaching consensus, and statements with the most far-reaching dissensus. Agreement refers to the highest mean score on a statement (closest to +4) and disagreement to the lowest mean score on a statement (closest to -4). Consensus refers to the smallest difference in scores per statement (i.e., standard deviation) and dissensus refers to the largest standard deviation.

The strongest agreement is found for statements 14, 21, 26, 27 and 34. These statements address transparency of research methods, the contribution of science to society and the necessity of conducting more research on EMF, PM and AMR. The strongest disagreement is found on statements 11, 12, 22, 24 and 28. These statements indicate that science and policy should not be strictly separated, experts should not incorporate personal values into their policy advice, and expert views on the risks of EMF/PM/AMR tend not to differ from those of colleagues.

The most far-reaching consensus was found on statements 1, 3, 26, 28 and 34. Among all 92 experts, the most unequivocal opinion concerned the necessity transparency in research methods and assumptions made when giving policy advice (statement 26, which is also one of the strongest 'agree with' statements; no expert strongly disagreed with this statement). Most experts agree that differences of opinion among experts should be made explicit when giving policy advice (again a plea for transparency). With a mostly neutral score, experts show consensus regarding the statement about cooperation with stakeholders in assessing the health risks of EMF/PM/AMR, as well as on the statement about expecting the government to coordinate the governance process for EMF/PM/AMR. Experts show overall *dis*agreement with the statement “my views on the risks of EMF/PM/AMR tend to differ from those of my colleagues”. No experts strongly agreed with this last statement, indicating that experts think they assess the risks similarly to their peers.

The most far-reaching dissensus was found for statements 19, 20, 22, 23 and 31. Experts strongly disagree regarding the idea that it is the primary task of a scientist to publish in peer-reviewed scientific journals. Great diversity was found regarding the best ways of dealing with the risks and uncertainties of EMF/PM/AMR. Statements 22 and 23 address the need for monitoring, additional regulatory measures and significant investment in precautionary measures. These statements were based on the classification proposed by Weiss (Weiss 2003). Finally, experts disagree on the contribution of future technological innovations to reducing the negative effects of EMF/PM/AMR on health and the environment.

3.4 Likert scale questions

Scores on the three Likert scale questions show the strongest consensus among PM experts (see Table 5 for scores on the Likert scale questions). The standard deviation on all three questions is relatively low for the PM group. In addition, the mean scores of the PM expert group are mostoutspoken. Relative to the other two groups, they show the highest degree of independence, the highest perception of the influence of their research on policy, and the lowest assessment of the degree of uncertainty about the health risks posed by PM. The AMR experts show the largest standard deviation with regard to uncertainty about health risks posed by their area of expertise. The EMF experts gave the lowest score to the question of whether they can give advice independently and uncensored by their corporate hierarchy.

Table 5. Likert scale scores on questions about factors possibly associated with an expert's role

	Independence		Influence of research		Degree of uncertainty	
	Mean	STD	Mean	STD	Mean	STD
AMR	4,4	0,7	3,9	0,9	2,6	1,2
EMF	4,0	1,2	3,7	0,8	2,8	1,0
PM	4,6	0,8	4,1	0,7	1,8	0,7

3.5 Key scientific issues and policy advice

Experts were presented with two open-ended questions. The first question, "What would you call the key scientific issue in EMF/PM/AMR at this time?," resulted in one key scientific issue in the fields of EMF and PM and several key issues in the field of AMR. The key scientific issue for EMF was the health effects of exposure to EMF. Some experts specified the possible health effects, including electro-hypersensitivity, neurodegenerative diseases, cancer and negative effects on well being. The key scientific issue for PM was the health effects of different PM compositions. A few other issues were mentioned, including: the effects of traffic-related policies on health, drafting new standards, and defining socially acceptable levels of risk. For AMR, several issues were raised. In order of the number of times they were mentioned, the issues were: antimicrobial stewardship, which relates to surveillance of antibiotic use as well as the rational/prudent use of antibiotics to minimize unintended consequences such as emergence of resistance; lack of scientific knowledge about the emergence of antibiotic resistance; lack of new antibiotics or alternative treatment options; the importance of adequate diagnostic tests to be used by health care professionals; and finally, recognition and awareness of AMR as a societal problem that requires governance.

The level of consensus among experts about key scientific issues differs among the three groups, with strong consensus among PM and EMF experts and a more diversified view among AMR experts. The second open question, "If you were asked to provide policy advice on EMF/PM/AMR, what concrete policy measure would you recommend?," resulted in lists of policy recommendations. The answers were issue-specific and we therefore elaborated on the policy recommendations in the case-specific papers; see EMF (Spruijt, Knol et al. 2015) and PM (Spruijt, Knol et al. 2016).

4. DISCUSSION

To add data to the small empirical knowledge base regarding how experts address the request to provide policy advice under conditions of scientific uncertainty, we undertook case studies on the issues of EMF, PM and AMR. Our main research questions were: what are experts' views of their roles when providing policy advice on EMF/PM/AMR? What are the main similarities and differences among the views of experts on their roles in the fields of EMF, PM and AMR?

4.1 Main findings

We found six roles that we labeled as follows: (1) engaged scientist, (2) pro-science expert, (3) regulatory advocate, (4) humble scientist, (5) transparent expert and (6) issue advocate. The first three factors were dominated by specific fields (AMR, EMF and PM, respectively). Engaged experts highly valued scientific knowledge and stressed the importance of a continuous dialogue between scientists and policymakers. Pro-science experts strongly agreed that new policies should be based on scientific knowledge, that knowledge possessed by the general public is less valuable and that monitoring is the most suitable way to address the risks and uncertainties of EMF/PM. Regulatory advocates strongly agreed that possible health problems are best managed through legislation and regulation, that scientists should publish in peer-reviewed journals as their primary responsibility and that they are not responsible for maintaining a continuous dialogue with policymakers. Humble scientists strongly agreed that scientists should be humble about the role of science in solving societal problems and had modest judgments regarding most other statements. Transparent experts emphasized the importance of transparency regarding research methods and assumptions, explicating differences of opinion among experts, and informing policymakers about the science underlying policy advice. Finally, issue advocates focused on actively interacting with policymakers and politics; they were fairly neutral in regard to the policy measures that should be taken.

Q methodology asks participants to rank order statements in a forced distribution, which results in an overview of existing subjective view patterns in a group of people. The six observed roles show the dominant patterns of viewpoints that exist in the expert group we studied. The six roles demonstrate different views regarding both experts' willingness to act on uncertain risks and experts' roles in interacting with policy makers. The views in the observed factors range from "no need for additional measures or research" to "investment in additional regulation, legislation and research." This supports Weiss' theory (Weiss 2003). The observed roles also show support for Pielke's theory (Pielke Jr. 2007) that experts hold different views of their roles when interacting with policymakers in highly uncertain and politicized contexts. Views of the interaction between scientists and policymakers range from strict separation to continuous dialogue.

4.2 Sensitivity analysis

Two different methods have been described and advocated for the analysis of Q method data: the first is principal component analysis (PCA) in combination with a varimax rotation, and the second is centroid analysis in combination with a manual rotation. Both strategies include arbitrary selection criteria, such as the minimum number of respondents loading significantly on a factor and the threshold that determines whether a sort (i.e., an individual view) loads significantly on a factor. We tested both strategies on our data in a sensitivity analysis. Table 6 presents the results of the sensitivity analysis. We found a large overlap between the two approaches. Both of the analyses showed two very similar factors: factors 1 and 2. In the PCA analysis we found four other factors. One of them seemed to be split into two separate factors in the centroid analysis (factor 4 in the PCA analysis is split into factors 3 and 7 in the centroid analysis; indicated in blue in Table 6). Both of the analyses show substantial similarities in results. We decided to use PCA, based on the justification that we used PCA in previous studies and therefore comparison of analysis would be possible. In our previous studies, PCA enabled us to incorporate the highest number of experts into our analysis.

Table 6. Sensitivity analysis of Centroid analysis versus Principal component analysis; number of experts loaded on factors and explained variance

FACTOR	CENTROID	PCA	Explained variance	PCA.>0.5*	Factor no. Centroid => PCA**
1	20	14	14%	20	1=>1
2	12	13	9%	13	2=>2
3	4	10	12%	14	3=>4
4	16	7	9%	10	4=>5
5	3	6	9%	10	5=>6
6	15	5	6%	5	6=>3
7	4				7=>5
SUM	74	55	59%	72	

* Manually flagging of experts that did not load on any factor with the standardized PCA but are included with the criteria of factor scores of >0.5 on at least one factor.

** Correspondence of factors from Centroid to PCA is based on manual identification of sorts, i.e., particular experts.

Out of the 92 participating experts, 55 load significantly on one of the six factors. As the threshold that determines the number of significantly loading experts on a factor is somewhat arbitrary, we manually changed it to >0,5 and found that with a higher threshold 72 of the 92 participating experts load significantly on a factor (see Table 6 for the distribution of experts in both analyses). In both analyses, some experts remain that do not fit in any of the extracted factors. This means that in addition to experts that load on a single factor, there are experts that load significantly on more than one factor or that do not load on any of the described factors. We interpret this as a signal that although we can discern dominant patterns of expert roles, there is a broader range of views on the role of scientific experts who provide policy advice.

4.3 Selection of experts

We used a structured expert selection procedure, based on nominations from the top 50 published experts in their fields. The nomination process resulted in two groups: singly and multiply nominated experts. This raises the question whether all experts should be treated equally or whether the judgments of some should be rated more highly than others (differential weighting cf. (Bolger and Rowe 2015)). Because we cannot assess the extent to which the consulted experts are engaged or influential in the policy arena, we decided to give all experts equal weight.

We observed differences in the nominees among the different fields. For AMR, the number of nominated experts was highest (132), while the number of multiply nominated experts was lowest. For PM, the number of nominated experts was 98 and the number of multiply nominated experts was highest (up to 12 nominations per expert), which indicates that the consensus among nominators regarding the top international experts in a particular field is diverse. Out of the multiply nominated PM experts, 58% participated; from the multiply nominated EMF experts, 41% participated. For AMR, this rate was 28%. In conclusion, compared to the other two fields, the sample of PM experts is more broadly supported by the selection of the top 50 published authors. We speculate that this is partly a consequence of the current stages of development of the fields, ranging from a well established field with longer traditions (PM) to newer developing fields like EMF and AMR. This may also explain why AMR experts nominated more key scientific issues in the open questions than did the experts from the other two fields.

4.4 Comparison of theory and empirical data

The factors with the largest number of significant loadings and highest explained variances in the case-specific analyses are also found in the overall PCA. More specifically, factor 2 (pro-science expert) and factor 3 (regulatory advocate), as described in this paper, show strong similarities with, respectively, factor 2 in the EMF analysis and factor 1 in the PM analysis. Factors 1, 4, 5 and 6 in this paper show combinations of factors from the previous case-specific analyses.

In our earlier literature review, we identified a number of notions and ideal-typical classifications of expert roles, particularly those of Wildavsky, Pielke and Weiss (Spruijt, Knol et al. 2014). This review also identified a number of suggestions from different schools of thought for improving the ways in which experts (should) advise on complex issues. These suggestions include the following: (1) Transparency in methods and assumptions; (2) Professional attitude of humility; (3) Explicating different points of view within the expert community; (4) Democratizing science (i.e., stakeholder dialogues); (5) Public participation; and (6) Precautionary principle. We developed our Q method statements based on these notions and classifications. Among the participating experts, broad consensus was observed on the necessity of being transparent about methods and assumptions. We also found support for the view (represented in the literature) that there is no strict separation between science and policymakers, but rather that the two are interlinked (not in the sense of "speaking truth to power" but rather engagement in continuous dialogue).

Views regarding the importance of a professional attitude of humility were diverse: engaged scientists see no need to be humble, whereas experts who loaded on the factor 'humble scientist' obviously hold an opposite view. A diverse view was also found regarding the notion that different points of view within the expert community should be made explicit: transparent experts most strongly agree with this statement and issue advocates slightly disagree. Views on public participation and democratizing science were also diverse. In general, we observed no strong support among experts for initiating public participation. There was some support for assessments of scientific output by an extended peer community of all affected parties. Finally, extremely different views were found regarding the precautionary principle. Pro-science experts and regulatory advocates hold completely opposing views on the statement that the risks and uncertainties of EMF/PM/AMR warrant significant investment in precautionary measures.

The dissensus statements showed empirical evidence for Weiss' theoretical assumption that experts differ in their willingness to act and assessment of the necessity to act regarding uncertain risks. Great diversity was found on the best ways of dealing with the risks and uncertainties of EMF/PM/AMR. Views ranged from supporting the need to monitor, to supporting additional regulatory measures, to supporting significant investment in precautionary measures.

CONCLUSIONS

To our knowledge, this is the first empirical study on expert roles in three different environmental health fields. We used a structured two-stage expert selection process. Our results support theoretical notions from the literature, but our empirical evidence shows an even richer variety than the classifications found in the literature. Experts generally agreed that they should be transparent about their research methods and assumptions made when giving policy advice. There are marked differences in views about whether and how experts should interact with policymakers, about whether to interact with stakeholders and about the need for/usefulness of various action perspectives on uncertain health risk problems. Some of these views were more dominant in one field than another. A particularly contested issue was the need for precautionary actions in response to uncertain health risks.

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APPENDIX

Q sort values for each statement by factor.

No	Statement	Factor/ Role					
		1: Engaged scientist	*2: pro-science expert*	*3: regulatory advocate*	*4: humble scientist*	*5: transparent expert*	*6: issue advocate*
1	As an expert, I think I should cooperate with stakeholders in assessing the health risks of EMF/PM/AMR.	2	0	**-1**	1	0	0
2	I feel personally motivated to initiate stakeholder cooperation in my research on EMF/PM/AMR.	1	-1	-2	-1	0	3
3	I expect the government to coordinate the governance process on EMF/PM/AMR.	0	2	0	1	**-1**	0
4	I think that possible health problems concerning EMF/PM/AMR are best managed by legislation and regulation.	-1	0	**3**	**1**	**-4**	-2
5	In my opinion, public health and environmental problems related to EMF/PM/AMR are too complex for only evidence-based policy.	-2	-3	-4	**0**	**1**	-2
6	As an expert, I should take the perspectives of the general public into account in my research.	0	**-3**	-1	0	-1	1
7	As an expert, it is my duty to maintain continuous dialogue with policymakers.	**3**	0	**-2**	0	0	0
8	As an expert, it is my responsibility to inform policymakers about all possible policy options and their potential consequences.	3	0	0	-1	2	1
9	As an expert, it is my task to recommend the policy option that I consider best.	1	**-1**	2	**-2**	1	**4**
10	I try to use my scientific knowledge to actively direct policy.	0	-2	0	-2	0	**3**
11	In my opinion, science should be limited to systematic knowledge production.	-4	**1**	**-1**	-4	-3	-3
12	I think there should be strict separation between scientists who do research and policymakers who build policy on that research.	-4	-1	-2	-3	-1	**-4**
13	When scientific knowledge is inconclusive, I think policymakers have the task of dealing with the resulting uncertainty.	**-1**	2	1	3	2	2
14	I think that scientific research should contribute to solving societal problems.	2	3	2	4	1	4
15	My only involvement in politics is to address specific questions posed by policymakers.	-2	0	-1	0	0	**-4**
16	I think that public anxiety is a good motivation for policy action, even when there is no scientific explanation for the anxiety.	-1	-3	-3	-2	-1	**0**
17	In my opinion, knowledge of the general public is of less value to policymakers than expert knowledge.	-1	**1**	0	-2	-2	-1
18	If the health and environmental impacts of a project involving EMF/PM/AMRs were highly uncertain, I would advise precautionary measures to protect public health and the environment.	1	**-1**	1	0	2	0
19	I expect future technological innovations to reduce the negative effects of EMF/PM/AMR on health and the environment.	3	0	**1**	3	**-4**	-1
20	I think new policies on EMF/PM/AMR should be based entirely on the best available scientific knowledge.	**4**	**4**	**0**	-1	**2**	-2
21	I believe the risks and uncertainties of EMF/PM/AMR warrant significant investment in additional research.	4	**-2**	**2**	4	4	**-1**
22	I believe the risks and uncertainties of EMF/PM/AMR require monitoring but there is currently no need for additional regulatory measures.	-3	**4**	**-4**	-3	-2	**0**
23	I believe the risks and uncertainties of EMF/PM/AMR warrant significant investment in precautionary measures	2	**-4**	4	0	1	**-3**
24	In addition to scientific knowledge, I preferably incorporate my personal values in my policy advice.	-1	-2	-3	-4	-3	0
25	I think policymakers are best supported when experts are transparent about their personal preferences with regard to the policy alternatives and the motivation for these preferences.	1	1	1	**-1**	3	2
26	In giving policy advice, I think experts should be completely open about the methods they use and	2	3	3	2	**4**	2

	assumptions they make.						
27	I think I should inform policymakers about the science underlying my policy advice.	1	3	2	2	1	1
28	My views on the risks of EMF/PM/AMR tend to differ from those of my colleagues.	-2	-4	-3	-3	-1	-1
29	I agree with current policies on EMF/PM/AMR.	-3	2	-2	1	-3	1
30	I am very interested in the political debate surrounding my research.	0	-1	0	0	-1	**3**
31	I think the primary task of a scientist is to publish in peer-reviewed scientific journals.	**-3**	1	**3**	-1	0	1
32	I think scientists should be humble about the role of science in solving societal problems.	**-2**	0	-1	**3**	1	2
33	I think that scientific output should be assessed by an extended peer community of all who are affected by the issue.	0	-2	-1	**2**	0	-2
34	I think that differences of opinion among experts should be made explicit when giving policy advice.	1	1	1	2	**3**	**-1**
35	Just as NGOs and industry do, I think scientists should actively approach politicians to present their points of view on EMF/PM/AMR.	0	-1	0	-1	**-2**	-1
36	I think scientists should 'speak truth to power' in their policy advice.	0	1	1	1	0	1
37	I think policymakers are best served when experts strive for consensus in their policy advice.	0	0	0	1	-2	-3
38	I primarily work in science because I like the intellectual challenge.	-1	**2**	4	0	3	0

* factor scores in bold are distinguishing statements

7

General discussion

Fact-based policies based on solid uncontested scientific evidence. For many people, this may sound as the ideal relation between science and policy. However, this ideal world does not hold for complex environmental health risks. In such cases, when science is contested or incomplete, scientists can take different roles when they advise policymakers. They may choose to advocate the policy option they consider best, or instead present all possible options. They may feel they should involve a broad range of stakeholders, or instead may just think they should stick to publishing in scientific journals. In this thesis, we presented research on the different roles experts may take when advising on complex environmental health risks. We added an empirical database to prior theoretical work on expert roles.

The main goal of the research presented in this thesis was to empirically assess the existence of expert roles and viewpoints. The main research question was "*What are the different views of scientific experts on their role as policy adviser on complex environmental health issues?*" Specifically we looked at experts on the issues of electromagnetic fields (EMF), particulate matter (PM) and antimicrobial resistance (AMR). These cases were selected as examples of current health risk problems, with different levels and forms of scientific uncertainty. The research question was studied in a three-pronged approach: a pilot study, a literature review and three surveys among recognized experts in these three fields. We also explored whether there are differences between scientific expert communities that study different complex issues.

In this general discussion we will zoom out a little and attempt to answer the following questions:

- What are the main research findings of our study?
- How does our empirical data relate to theoretical notions?
- How robust is the selection of experts?
- What are the strengths and limitations of the used methodology?
- What are the implications of our research findings?

MAIN RESEARCH FINDINGS

The pilot study on expert roles among Dutch PM and EMF experts (Chapter 2) was the first of its kind and revealed significant differences in roles among experts, particularly regarding agreement about the necessity and utility of different ways of policy intervention (i.e., precaution, more research). The literature review (Chapter 3) showed that publications on scientific experts who provide policy advice affirm that experts (should) hold different roles, depending on factors such as the complexity of the issue at stake, the type of knowledge and values that the experts have and contextual factors--the types of organizations in which experts are employed or the broader societal context. The literature review also showed that research on expert roles has remained largely theoretical.

In summary, several scholars have discussed the various potential roles of experts in the interplay between science and policy. Wildavsky's (Wildavsky, 1979) famous phrase "speaking truth to power" suggests a clear division of tasks between science and politics. According to Wildavsky, scientific experts should communicate objective and true knowledge to politicians. Jasanoff (Jasanoff, 1990), however, states that "the notion that scientific advisors can or do limit themselves to addressing purely scientific issues seems fundamentally misconceived", because the idea of the completely value-free scientist is outdated and the relationship between science and policy is intricate. Pielke (2007) and Weiss (2003, 2006) proposed classifications of expert roles with four and five categories, respectively.

We studied 267 papers related to expert roles and policy advice. The scientometric analysis in the literature review demonstrated the existence of different schools of thought and citation communities, such as Post-normal science, Science and technology studies, Science policy studies, Politics of Expertise and Risk governance. Scholars predominantly cite work within their school of thought, with little references to pertinent publications on the same topic from other schools of thought. In general, the authors in the different schools of thought agree on the changing positions of science and scientific experts in society i.e., the focus on socially robust knowledge and democratization of knowledge. This focus leads to calls for transparency and more generally to 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, personal 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 several factors.

The pilot study and the three surveys add empirical data to the, so far, mainly theoretical debate. The survey among international EMF experts confirmed that different distinct roles and viewpoints exist within their community (Chapter 4). The study suggested that the indicated level of uncertainty was one of the factors associated with the EMF expert' roles and, most likely, their policy advice. The survey among international PM experts (Chapter 5) also confirmed different roles and viewpoints within their community, although the different views on their roles as science advisers are found less divergent than for EMF. Compared to experts in the fields of EMF and AMR, PM experts shared a broad consensus that, based on scientific research, more stringent policies should be imposed to reduce health impacts (of air pollution). Most important differences within the PM expert community are related to their views on appropriate levels of interaction with policymakers and other stakeholders, and to their preferred professional attitude (humble or not). Finally, the survey among AMR experts showed four expert roles. Experts working in human medicine and experts working in veterinary medicine form separate roles, indicating that they hold different views on their role as science adviser. The intention is to tackle AMR with a One Health approach, meaning that health and well-being will be improved through cooperation between medical doctors, veterinarians and other relevant stakeholders. Based on our findings these groups hold different views on the key scientific issue as well as on the most necessary measures to take (e.g., focus on new diagnostic methods, reduced prescription, better manage bacteria and pharmaceuticals in waste, financial incentives for pharmaceutical companies, or surveillance of antibiotic use). Awareness of these differences could contribute to the successful execution of a One Health approach.

COMPARISON OF EMPIRICAL DATA AND TYPOLOGIES IN THE LITERATURE

In the overall analysis of the three surveys, the first three factors (i.e., roles) were dominated by experts from one of the domains. These three factors represent the groups with the largest number of experts and the highest explained variance (for details see Table 3 in Chapter 6). This finding corresponds to findings from our literature review that 'type of issue' and 'type of knowledge of the expert' are factors that influence the role of an expert (for details see Table 1 in Chapter 3). This is notable, because the Q-statements were identical for all experts and their expertise was not included as a variable in the analysis. We can only speculate about the reasons for these observed differences. Apart from being artifacts (e.g., chance observations), the differences may stem from differences in historic developments of the fields with respect to research as well as policy and regulation. Also the research funding of (regulatory) sciences may differ between the fields, which may affect career paths of scientistis involved. The differences may also result from 'group think' within relatively tight communities. Literature furthermore suggests that the core values of an expert influence their role, which may affect which particular field of study an expert might choose. That selection process could separate people into groups with differing worldviews. Our study does not allow analysis on these aspects. We did observe some differences between the groups of experts. There were differences in expert nomination between groups, differences in gender distribution and differences in policy advice as primary task. There also appeared to be more consensus among PM experts than in the other two groups of experts. Further research is needed to a) confirm whether the observed pattern is corroborated in other studies, and b) to analyze the underlying determinants of such patterns.

The literature review showed different schools of thought. The five schools we identified all describe the need to democratize science (e.g., stakeholder dialogs) where only one of the schools (i.e., risk governance) explicitly discusses the precautionary principle (see Table 1 and 2 in Chapter 3 for more details). Three of the five schools of thought stress the importance of transparency by communication of methods and assumptions made by the experts as a way to improve expert advice on complex issues. The vast majority of participating experts in the surveys agreed with that. Two schools of thought suggest a professional attitude of humility for experts that give policy advice. Among the observed expert roles, views varied on whether scientists should be humble. The suggestion made by three schools in the literature to explicate different points of view within the expert community received scores around +1, indicating not a very strong agreement nor disagreement. In summary, several of the ideas presented in the literature were supported by our data, in particular with respect to 'type of issue' and 'type of knowledge of the expert' as factors that influence experts' roles. We also observed broad support for the need for transparency about methods and assumptions when giving policy advice.

SELECTION OF EXPERTS

For the pilot study we selected Dutch experts based on their knowledge of the scientific discourse and professional activity on either PM or EMF. The recruitment process consisted of contracting members of national committees, university researchers and other scientific institutes, and additional experts identified through the network of the Dutch National Institute for Public Health and the Environment (RIVM). For the next three international surveys we used a structured expert nominee process to structure the selection process and improve transparency.

Looking at the background variables (see Table 2 in Chapter 6 for details) of the participants of the surveys we see that epidemiologists and public health experts are strongly represented in all expert groups. In addition, more issue specific fields of expertise are represented in all groups. Female experts were least strongly represented in the field of AMR (7%) and strongest in the field of EMF (41%). The mean age of all experts was 56, with small differences between cases. The Dutch experts in our pilot study had an average age of 47, with no differences between cases. The literature suggests that expertise is based on experience (Mieg 2009) and that people become experts after at least ten years of deliberate practice (Ericsson and Lehmann 1996). We did not ask participants in our studies the number of years of practice in their particular field. Therefore we cannot draw firm conclusions, but the mean age of the participating experts as well as the two-stage nomination process, makes experience in their field of interest plausible.

Both for the EMF and the PM survey we compared our list of respondents with other expert groups or consultations. Due to time constraints we did not make such a comparison for AMR. For EMF we compared our list of respondents to the membership lists of the ICNIRP and the BioInitiative participants (HCN 2008). The results suggested a relationship between involvement with one of these groups and the attributed expert roles. For PM we compared our list of respondents with participants of previous expert consultations that took place between 2007-2013 (Cooke, Wilson et al. 2007, Roman, Walker et al. 2008, WHO 2013). The results show that 14 out of the 31 participants in our consultation also participated in earlier expert consultations. Earlier consultations mostly included a smaller number of experts and, except from the consultation by the WHO, included either experts from the US or EU. Therefore, it is not surprising that there are some differences in the composition of the consulted expert groups. We conclude that the overlap in experts between our participant list and participants of previous elicitations is an indication of a solid selection process.

METHODOLOGICAL CONSIDERATION; STRENGTHS AND LIMITATIONS

One of the main strengths of our study is the collection and analysis of empirical data on expert roles in groups of international renowned experts on EMF, PM and AMR, using Q methodology. The statements were based on an extensive literature review and on an earlier pilot study among Dutch scientists. For the three case studies, experts were selected through a structured approach where the top-50 most published authors in the preceding ten years nominated colleagues. The nomination process allowed inclusion of recognized (generalist) experts in the field who do not necessarily publish original research under their own name.

Q methodology includes the formulation of a concourse: a set of statements representing the most prominent subjective views on a specific issue. We compiled our concourse based on typologies of Pielke and Weiss and on our review of the literature. We deliberately chose for a broad approach. Downside of this approach is that we could not empirically 'test' Pielke's or Weiss' typology because their ideas were supplemented with other theoretical ideas from the literature. Testing their ideal-types would have requested a concourse with only statements based on the respective typologies. Our concourse did allow to study the existence of different expert roles with a broader view. We found some evidence for both Pielke and Weiss perspectives as well as for other factors that, according to the literature, influence the role of an expert. Other factors that were part of the concourse included the complexity of an issue (i.a., level of scientific uncertainty), transparency in methods and assumptions, public participation and a professional attitude of humility. The literature on science-policy interaction also covers topics not addressed in our Q statements, we made choices to limit the burden to the participating experts. Thus, the role of power, formation of advocacy coalitions within expert committees, political orientation or status in the scientific community are known topics from the literature, but are not incorporated in this thesis. For similar reasons, we restricted the number of additional questions, which precluded analysis of determinants of the observed patterns in expert's roles. These aspects require further research.

Q methodology asks participants to rank order a set of statements. Participants are forced to evaluate statements relative to each other. For example, two statements can be assessed as strongly agreed with (score +4--see Figure 2 in Chapter 2 for an example of score sheet). In case a participant judges more than two statements as strongly agreed with s/he has to move statements to the next column (score +3). In the extreme and unlikely case that a participant agrees with the full set of statements s/he is forced to give some of the statements a score of -4 (meaning strongly disagree with). This means that the scores and level of agreement are relative. An assumption of Q methodology is that a well-designed concourse consists of statements that a participant agrees with as well as other statements the participant disagrees with. The first step of subdividing the complete pile into agree, disagree and neutral confirms that, although not everyone's 'agree pile' had the same number of statements as boxes on the score sheet, participants indeed agreed with part of the statements and disagreed with another part.

The broad set of statements that we compiled and used for three surveys could be used to study other complex environmental health issues. We chose the topics of electromagnetic fields, particulate matter and antimicrobial resistance. These cases were chosen because they are all complex environmental health issues surrounded by scientific uncertainty. The list of complex issues that could be studied is longer. Other issues could easily be studied using a similar set of statements. Issues that qualify are, for example, nanotechnology, endocrine disrupters and climate change. Another possible application of the compiled set of statements is applied research: the ranking of statements could be used as a personal or group assessment that forms the basis for debate among professionals about their role and role perceptions.

The flipside of collecting data using Q methodology is that we collected information as stated by respondents, but we did not study actual behavior e.g., actual lines of reasoning in expert committees or argumentations used when experts and policymakers interact. Participative observation of an advisory committee would be an alternative method to gain empirical data on roles experts hold (Owens, Rayner et al. 2004). Another possibility would be discourse analysis of formal advisory reports. Such an analysis would provide insight in actual advice given. However, discourse analysis of formal advisory reports may not reveal the individual roles and positions taken, since typically such reports give consensus opinions and do not provide the full scope of views held by all individual members. Also, outcomes of participative observation of an advisory committee may be more difficult to generalize to committees with different compositions and scopes.

The choice for Q methodology allowed us to study three international expert groups covering specific issues with a wider scope than possible within a specific scope of a committee or a committee report. A participatory approach within the framework of this thesis would only have allowed observations in one or two advisory committees. Besides, Q methodology supports geographically dispersed experts to be part of our study. Where participative observation and discourse analysis allow for more in-depth study of specific committees or reports, we chose Q methodology to be able to inquire more issues on a larger geographical scale. To follow up on our study, more in-depth studies of argumentation in expert committees would be of interest, to analyze how expert views are presented in practice.

Other limitations involve differences between stated roles and attitudes as observed in our study and the actual behavior and argumentation of experts in the day-to-day practice of giving policy advice about uncertain risk problems. Also, in this study the focus was on experts alone. In practice, the role, attitude and actual behavior of experts is determined by peer pressures and interactions, by expectations and demands from policymakers, from stakeholders and from the social environment of experts, from family and friends. Future research into the determinants of the observed roles, attitudes and actual behavior is warranted.

IMPLICATIONS OF RESEARCH FINDINGS

Overall, we conclude that the existence of different expert roles is evident from the empirical data presented in this thesis. This insight has implications for further research and possibly for the organization of expert advice. Further research should confirm these observations, since there is little other empirical data to go on. Alternative approaches to our Q method approaches, e.g. argumentation analysis, observation of roles and actual behavior of experts in expert committees, research into the determinants of expert roles merit consideration. Our study focused on the scientific community i.e. experts providing policy advice on uncertain environmental health risk problems. We do not know at this point what the expectations and information needs of policy makers and stakeholders are with respect to expert roles. This also merits further study.

We observed that experts themselves may be unaware of the normative aspects in their advice. For instance, while most PM experts considered their views on the risks of PM to be in line with those of their colleagues, four distinct expert roles were observed. Our empirical observations provide further substrate for a debate amongst professionals about conflicts of values and the different ways in which bureaucratic and academic organizations function (time horizons, communication styles, etc.) (Merton 1945). Such debate may also clarify confusion about interpretative ambiguity and normative judgements, which now remain often implicit in argumentation about the need for (precautionary) action. We argue that normative aspects should be more explicitly addressed in the process of giving scientific policy advice; this is in line with the broad appeal for transparency, both in the literature and among our respondents. Also, in the academic curricula and post-graduate training, explicit discussion about differences in expert roles merit wider attention. Moreover, in the composition of expert committees, not only the different disciplines need addressing, also the representation of different expert roles need consideration.

Expert committees in which only one or two expert roles are represented may provide unbalanced and biased results with respect to available action perspectives for policymakers and stakeholders. A committee dominated by 'early warners', a role recognized among EMF experts, will likely lead to calls for precaution while one dominated by 'status quo' expert would see no need for further regulatory action. The composition of scientific advisory committees is generally based on a set of criteria such as their individual knowledge base, their status as authorities within their field of study, and their willingness to put their knowledge at society's disposal in a disinterested way (Hendriks, Bal et al. 2004). Expert roles could be added as selection criteria. A committee consisting of experts representing all dominant views and roles is more likely to present robust advice—advice that is broadly supported. Existing dissenting or opposing views within an expert community (or committee) makes consensus advice sometimes difficult to achieve. When consensus is impossible differences of opinion among experts should be made explicit, according to three of the schools of thought found in the literature review and also according to most of the participating experts in this study (only issue advocates slightly disagree). This could be explicitly asked from future committees, although it is well known that the presentation of several policy options by scientists is not always what policymakers, politicians or other stakeholders ask for.

IN CONCLUSION

This thesis and its empirical data demonstrate the existence of different expert views on the role of experts as policy advisor. These views are partly specific to the fields of EMF, PM and AMR. The theoretical ideal-typical roles from the literature can indeed be identified, but the empirical evidence shows a richer variety than the classifications from the literature. Future research needs to confirm these observations. Scientists generally do not think their views on risk tend to differ from those of their colleagues. Nonetheless, different views can be observed. We argue that there is a need for more explicit discussion and consideration of expert roles, within the scientific community, academic curricula, with stakeholders and within the science-policy interface.

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Samenvatting

Summary in Dutch

Perspectieven van wetenschappers op hun rol als beleidsadviseur bij complexe milieu-gezondheidsvraagstukken

Achtergrond en onderzoeksvraag

Beleid dat tot stand komt op basis van objectieve en onbetwiste wetenschappelijke kennis; dat klinkt als de ideale relatie tussen wetenschap en beleid. In de praktijk blijkt dat het bij complexe milieu-gezondheidsrisico's niet zo werkt. Kennis over milieu-gezondheidsrisico's is vaak onzeker. Deze wetenschappelijke onzekerheid biedt ruimte voor experts om op verschillende manieren om te gaan met de vraag van beleidsmakers om advies te geven over gezondheidsrisico's. Beleidsmakers vragen bijvoorbeeld: 'Mag een zendmast op een basisschool geplaatst worden gezien de mogelijke effecten op de gezondheid van kinderen?'. Of 'moet de snelheidslimiet voor verkeer worden aangepast om de gezondheidseffecten van luchtverontreiniging te beperken?' en 'hoe beperken we de toenemende dreiging van antibioticaresistentie?'.

Wanneer de wetenschappelijke kennis onzeker is blijkt dat wetenschappers bij zulke vragen verschillend naar hun rol als beleidsadviseur kijken. De een houdt zich strikt aan de, vaak onzekere, feiten. De ander geeft zijn persoonlijke opvatting. Bijvoorbeeld dat uit voorzorg maatregelen genomen moeten worden. Of dat er eerst spijkerhard bewijs moet zijn voordat er kosten gemaakt worden voor maatregelen. Tot voor kort waren hier geen gegevens over, alleen theorieën. Dit proefschrift voegt empirische data toe aan die theorieën. De hoofdvraag van het onderzoek was: wat zijn de verschillende perspectieven van wetenschappers op hun rol als beleidsadviseur bij complexe milieu-gezondheidsvraagstukken? Het proefschrift beschrijft een onderzoek onder internationale experts op het gebied van electromagnetische velden (EMV), fijnstof (PM) en antimicrobiële resistentie (AMR). Deze drie onderwerpen zijn gekozen omdat het allemaal actuele milieu-gezondheidsvraagstukken zijn met een verschillende mate van wetenschappelijke onzekerheid.

Drie complexe milieu-gezondheidsvraagstukken

Electromagnetische velden (EMV) worden geproduceerd door natuurlijke en door de mens gemaakte bronnen. Te denken valt aan radio, televisie en mobiele telefoons. Mensen worden in toenemende mate blootgesteld aan een veelvoud van dergelijke bronnen (bijvoorbeeld WiFi). Deze ontwikkeling heeft geleid tot de vraag of blootstelling in de algemene bevolking leidt tot negatieve gezondheidseffecten. Wetenschappelijk bewijs voor die relatie is zwak. Maar aangezien de technologische ontwikkelingen recent zijn en zeer snel bestaat er onzekerheid over mogelijke lange termijn effecten. Het huidige beleid is dan ook gevormd tegen een achtergrond van wetenschappelijke onzekerheid.

Fijnstof (PM) bestaat uit een mengsel van stofdeeltjes met verschillende vormen, chemische samenstellingen en fysische en biologische eigenschappen. Fijnstof komt, net als EMV, zowel vrij in de natuur voor en als gevolg van menselijk handelen. De kwaliteit van de buitenlucht is in de Westerse wereld sterk verbeterd in de afgelopen decennia, als gevolg van milieubeleid en technische maatregelen en ontwikkelingen (bijvoorbeeld roetfilters voor dieselmotoren, hybride en elektrische motoren).Tegelijkertijd is het wetenschappelijke bewijs voor de negatieve gezondheidseffecten van de huidige blootstellingen aan fijnstof toegenomen en is de ziektelast van PM substantieel. Onzekerheid bestaat vooral over de precieze relatie tussen verschillende fijnstofdeeltjes en precieze gezondheidseffecten.

Antimicrobiële resistentie (AMR) is de ontwikkeling van bacteriën tot varianten die ongevoelig zijn voor antibiotica. Sinds 1928 vormen antibiotica een essentieel onderdeel van de Westerse geneeskunde. Wereldwijd is een trend zichtbaar van een toenemend aantal patiënten met een infectie met een resistente bacterie. Deze patiënten zijn moeilijker te behandelen en zijn hierdoor vaak langer ziek of zelfs onbehandelbaar. Het is op dit moment onduidelijk via welke route resistente bacteriën zich precies verspreiden (mens-op-mens, via dieren, voedsel en/of het milieu). Daarnaast is ook onzeker welke alternatieve behandelmethoden het meest kansrijk zijn. Waar bij EMV en PM nationaal en internationaal beleid gevoerd wordt hebben bij AMR medisch specialisten en dierenartsen de taak om beleid te maken. Voor alle drie de onderwerpen geldt dat ze zich niet laten beïnvloeden door landsgrenzen.

Methoden

Het onderzoek is uitgevoerd in drie delen: een pilot studie onder Nederlandse EMV en PM experts (hoofdstuk 2), een literatuurreview (hoofdstuk 3) en drie surveys (hoofdstukken 4-6) die zijn afgenomen bij internationale experts. Voor de selectie van de internationale experts is gebruik gemaakt van een gestructureerd selectie en nominatie proces. Allereerst zijn de vijftig wetenschappers die het meest hebben gepubliceerd over één van de drie onderwerpen in de laatste tien jaar op een rij gezet. Vervolgens is aan die vijftig mensen gevraagd om zowel inhoudsdeskundigen als generalisten te nomineren. Generalisten zijn mensen die veel van een onderwerp weten en daarnaast actief zijn in beleid (bijvoorbeeld bij de WHO, EU of op nationaal niveau). Alle genomineerden zijn gevraagd deel te nemen aan de survey.

De pilot studie en surveys zijn uitgevoerd met behulp van de Q methodologie. De Q methodologie is een manier om subjectiviteit te onderzoeken. De methode behelst het verzoek aan deelnemers om een set van subjectieve stellingen te beoordelen op een schaal van heel erg eens tot heel erg oneens. Een voorbeeld van een stelling die deelnemers moesten beoordelen is: "Ik denk dat de risico's en onzekerheden rondom EMV/PM/AMR vragen om monitoring en dat er geen reden is voor het nemen van verdere maatregelen". Of: "Als expert mag van mij verwacht worden dat ik een continue dialoog aanga met beleidsmakers". De set met stellingen worden door iedere deelnemer in een geforceerd quasi normaal verdeeld patroon gelegd (zie Figuur 2 in hoofdstuk 2 voor een visualisatie van dit patroon). De patronen van alle deelnemers worden geanalyseerd en de uitkomst van de analyse is een aantal clusters van vergelijkbare patronen. Dat wil zeggen dat deelnemers die samen een cluster vormen de totale set van stellingen op een vergelijkbare manier hebben beoordeeld.

De literatuurreview die zich over verschillende wetenschapsgebieden uitstrekte, is uitgevoerd met behulp van een zogenaamde scientometrische analyse. Daarmee is gekeken naar patronen in gepubliceerde literatuur over expert rollen. Specifiek is een co-citatie analyse uitgevoerd om de literatuur te structureren op basis van referenties die auteurs gebruiken. Co-citatie wil zeggen dat Auteur A en Auteur B allebei verwijzen naar publicatie X. Hoe hoger het aantal publicaties waar A en B allebei naar verwijzen, hoe sterker de auteurs met elkaar verbonden zijn.

Resultaten

De literatuurstudie laat zien dat er meerdere wetenschappelijke disciplines zijn die publiceren over expert rollen. De co-citatieanalyse resulteerde in vijf groepen van auteurs die veel overlap laten zien in de publicaties waar ze naar verwijzen, maar verschillen van de andere groepen. Deze 'citatiegemeenschappen' hebben we gelabeld als: 'post-normale wetenschap', 'wetenschap en techniek', 'beleidswetenschappen', 'politiek van deskundigheid' en 'risico governance'. Publicaties van deze vijf citatiegemeenschappen tonen overeenstemming over de volgende onderwerpen: de rol van een expert wordt beïnvloed door het type probleem waar advies over gevraagd wordt en door andere partijen (algemene publiek en andere betrokken partijen). Daarnaast is er overeenstemming over de noodzaak om het proces van wetenschapsbeoefening en het geven van beleidsadvies op basis van wetenschappelijke kennis te democratiseren. Met democratisering van kennis wordt bedoeld dat kennis wordt verworven en verspreid onder grotere delen van de bevolking dan alleen onder wetenschappelijke experts. Het idee van de ivoren toren waar wetenschappers onderzoek doen is het tegenovergestelde van democratisering van kennis.

Verschillen in de citatiegemeenschappen zijn bijvoorbeeld zichtbaar wanneer de auteurs het hebben over de noodzaak om verschillende perspectieven van experts expliciet te maken. Of wanneer gekeken wordt naar het voorzorgsbeginsel; slechts één van de vijf gemeenschappen bespreekt dit onderwerp. De literatuurstudie laat ook zien dat publicaties over de rol van wetenschappelijk experts bij het geven van beleidsadvies over complexe milieu-gezondheidsvraagstukken hoofdzakelijk theoretisch zijn. Empirisch werk ontbreekt nagenoeg.

De pilot studie en de drie surveys voegen empirische data toe aan bestaande theorieën. De pilot studie onder Nederlandse experts op het gebied van elektromagnetische velden en fijnstof laat duidelijke verschillen zien in rolopvattingen tussen experts. In het bijzonder wanneer ze gevraagd wordt naar de meest geschikte maatregelen (voorzorgsbeginsel, meer onderzoek etc.). Ook bij de drie surveys die werden afgenomen bij internationale experts werden verschillende rolopvattingen gevonden. De survey onder internationale EMV experts laat vier 'expert rollen' zien. De resultaten suggereren dat de inschatting van experts over de mate van wetenschappelijke onzekerheid samenhangt met hun opvatting over hun expert rol, en waarschijnlijk ook met het gegeven beleidsadvies. De survey onder internationale PM experts laat ook vier rollen zien binnen die gemeenschap. De verschillen tussen PM experts zijn minder groot dan bij EMV experts. In vergelijking met EMV en AMR experts hebben PM experts vergaande consensus over de noodzaak om verdergaande maatregelen te nemen om de luchtkwaliteit te verbeteren. De grootste verschillen tussen PM experts gaan over de interactie met beleidsmakers (veel of weinig) en of een bescheiden houding van experts wenselijk is. Ook de internationale survey onder AMR experts laat vier verschillende rolopvattingen zien. Er is een duidelijk verschil tussen experts met een veterinaire achtergrond en die met een achtergrond in de humane gezondheidszorg. Een vergelijkende analyse van de drie surveys laat zien dat expert rollen voor een deel onderwerp specifiek zijn. Deze bevinding correspondeert met het resultaat uit de literatuur review dat type onderwerp een factor is die de rol van een expert beïnvloedt. Andere factoren die van invloed zijn op expertrollen en zowel naar voren kwamen in de review als uit de survey zijn: type kennis van een expert en het belang van transparantie over wetenschappelijke aannames en onderzoeksmethoden.

Concluderend, uit de data gepresenteerd in dit proefschrift blijkt dat experts hun beleidsadvies niet alleen op wetenschappelijke kennis baseren, maar ook op persoonlijke opvattingen over het omgaan met risico's.

Conclusie

Hoofdstuk 7 van dit proefschrift sluit af met een algemene discussie. Hierin worden een aantal methodologische aspecten besproken en worden de resultaten geduid in het licht van de veelal theoretische literatuur. De resultaten van dit onderzoek tonen aan dat de ideaal-typische theoretische rolopvattingen inderdaad in de praktijk herkenbaar zijn. Tegelijkertijd laten de resultaten zien dat de variatie in opvattingen rijker en gevarieerder zijn dan de ideaal-typische theoretische classificaties. Een beperking van de gekozen onderzoeksbenadering is dat experts gevraagd zijn naar hun opvattingen. Of en in welke mate die opvattingen daadwerkelijk beleidsadviezen kleuren is niet onderzocht. Daarvoor zijn andere benaderingen nodig.

Opvallend is dat de geconsulteerde experts in meerderheid vinden dat hun opvattingen over de gezondheidsrisico's niet afwijken van die van hun collega's. Niettemin worden in alle drie de groepen en in de pilot verschillende patronen gevonden. Omdat behalve de drie onderzochte onderwerpen er meer complexe en onzekere milieu-gezondheidsvraagstukken zijn en dezelfde problematiek zich ook in andere kennisdomeinen zal manifesteren is de conclusie dat verschillen in rolopvatting meer aandacht moeten krijgen. Zowel bij adviezen van expert commissies, als in opleidingen aan universiteiten en bij maatschappelijke dialogen over complexe milieu-gezondheidsvraagstukken.

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About the author

Pita Spruijt (1984) started working on her PhD research in 2011. The research was executed as part of IRIDIUM, a joint research project of the Dutch National Institute for Public Health and the Environment (RIVM) and Utrecht University (IRAS) in the Netherlands. The interdisciplinary research project focused on expert views on scientific policy advice on complex environmental health issues, e.g., electromagnetic fields, particulate matter and antimicrobial resistance. As part of her PhD she gave presentations at national and international conferences and published in international peer reviewed journals. Next to her PhD she taught a course in the philosophy of science at the faculty of Social Sciences of Utrecht University.

Before starting her PhD research she studied sociology at the University of Amsterdam and at Utrecht University. In between her studies in Amsterdam and Utrecht, she temporarily left university to work on a European research project at RIVM. After finishing her PhD she started working as a postdoctoral researcher at the Centre for Infectious Diseases at RIVM. The focus of her current research is on the governance of antimicrobial resistance. The research is set up in collaboration with University College London.