# 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 she/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 disagreement 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.

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## 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, 2013; 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 et al., 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 et al., 2014; Cooke et al., 2007; Hoek et al., 2009; Roman et al., 2008; Tuomisto et al., 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 et al., 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, 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 policy makers 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 and Jenkins-Smith, 2007; Van Asselt and 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 et al., 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 et al., 2010). Fig. 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 and Maguire, 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
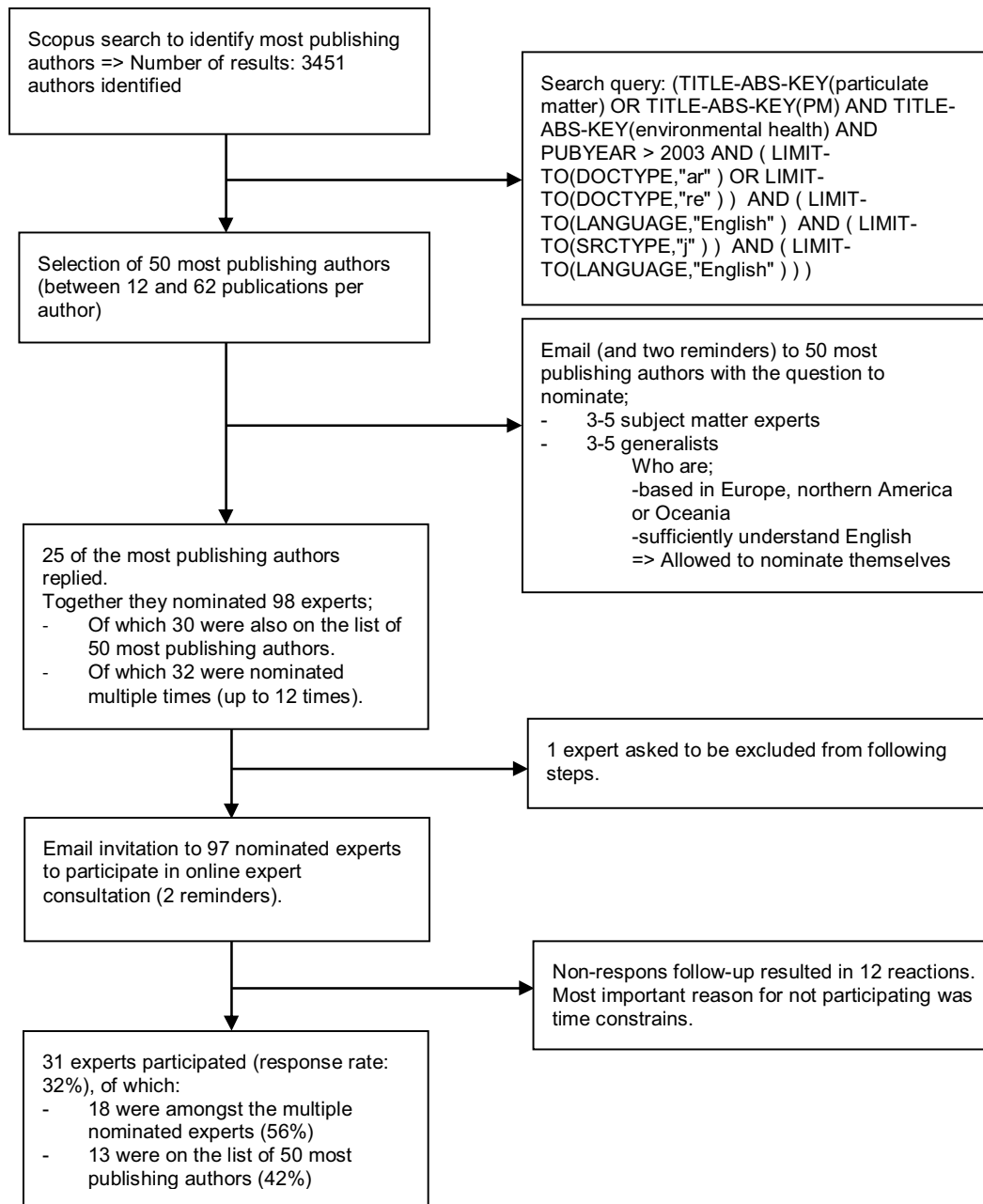
Scopus search to identify most publishing authors => Number of results: 3451 authors identified

Search query: (TITLE-ABS-KEY(particulate matter) OR TITLE-ABS-KEY(PM) AND TITLE-ABS-KEY(environmental health) AND PUBYEAR > 2003 AND ( LIMIT-TO(DOCTYPE,"ar" ) OR LIMIT-TO(DOCTYPE,"re" ) ) AND ( LIMIT-TO(LANGUAGE,"English" ) AND ( LIMIT-TO(SRCTYPE,"j" ) ) AND ( LIMIT-TO(LANGUAGE,"English" ) ) )

Selection of 50 most publishing authors (between 12 and 62 publications per author)

Email (and two reminders) to 50 most publishing authors with the question to nominate;
- 3-5 subject matter experts
- 3-5 generalists
    Who are;
    -based in Europe, northern America or Oceania
    -sufficiently understand English
    => Allowed to nominate themselves

25 of the most publishing authors replied.
Together they nominated 98 experts;
- Of which 30 were also on the list of 50 most publishing authors.
- Of which 32 were nominated multiple times (up to 12 times).

1 expert asked to be excluded from following steps.

Email invitation to 97 nominated experts to participate in online expert consultation (2 reminders).

Non-respons follow-up resulted in 12 reactions. Most important reason for not participating was time constrains.

31 experts participated (response rate: 32%), of which:
- 18 were amongst the multiple nominated experts (56%)
- 13 were on the list of 50 most publishing authors (42%)

**Fig. 1.** Flow diagram outlining the expert nomination and selection process.

methodology, see (Brown, 1993; Nicholas, 2011; Thomas and Baas, 1992).

### 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 et al., 2012). POETQ is a Partnership Online Evaluation Tool that employs the Q methodology. The 31 participating experts rank ordered the

**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**[a] | 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 policy makers | **−2** | **3** | 0 | 0 |
| 8 | As an expert, it is my responsibility to inform policy makers 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 policy makers who build policy on that research | −2 | −4 | −3 | **−1** |
| 13 | When scientific knowledge is inconclusive, I think policy makers 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 policy makers | −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 policy makers 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 |

[a] Numbers in bold are distinguishing statements.

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 Fig. 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).

### 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 labelled each factor. The PCA results were visualized using the R statistical software package (see Fig. 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 Fig. 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% were male and 26% 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 Fig. 3 for a visualization). These factors show differences between the views of groups of PM experts and yield a total explained variance of 61%. 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 Fig. 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% 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 policy makers. 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 scientists* (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% of the total variance. Like the regulatory advocate,

**Table 2**
Background variables of participants.

| Demographics | | |
| --- | --- | --- |
| Gender | Mean Age (standard deviation) | 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) |



| −4 | −3 | −2 | −1 | 0 | +1 | +2 | +3 | +4 |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |

**Fig. 2.** Example of score sheet for the rank ordering of all statements (forced quasi normal distribution).
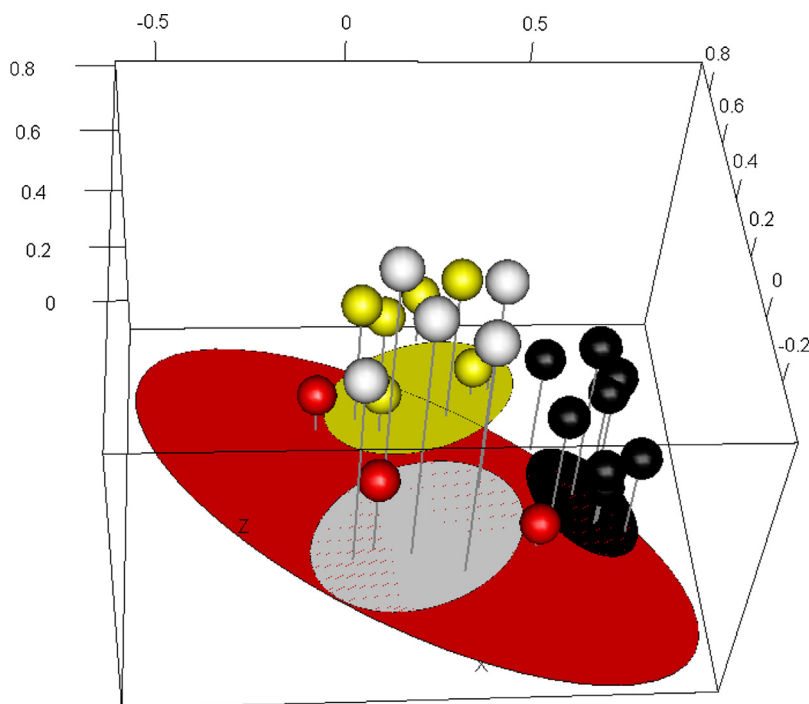
**Fig. 3.** Visualization of participants clustered in four roles: Regulatory advocate, 8 experts; engaged scientist,7 experts; humble scientist, 5 experts; and noninterventionist, 3 experts. The *X*,*Y* and *Z*-axes show the different roles with their factor scores. Note that the axis for the noninterventionists is not represented in the figure.

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 policy makers who build policies on that research. Furthermore, the engaged scientists agree that it is their duty to maintain continuous dialogue with policy makers, 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 disagree 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.

### 3.1.3. Role 3: humble scientist

The *humble scientist* role was shared by five experts and explained 14% 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 disagree 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 policy makers than expert knowledge. These experts disagree that it is their responsibility to inform policy makers of all possible policy options and of their potential

**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 respondents (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 <br> (−) 5 16 22 24 28 | 8 (22%) |
| 2 Engaged expert | Evidence-based policy; No strict separation between science and policy; Dialogue between experts and policy makers; Scientists should not be humble | (+) 7 18 20 26 27 <br> (−) 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 <br> (−) 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 <br> (−) 6 16 23 24 31 | 3 (9%) |

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 policy makers 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.

### 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 Figs. 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 policy makers 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* disagree 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 Fig. 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 (standard deviation 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 (standard deviation 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 (standard deviation 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 behaviours, 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 discussion

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 and Wilsdon, 2012; Owens et al., 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 et al., 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 and 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 and 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 policy makers and other stakeholders and to their preferred attitudes (humble or not).

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