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The ethos of post-normal science

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ABSTRACT

The norms and values of Post-Normal Science (PNS) are instrumental in guiding science advice practices. In this article, we report work in progress to systematically investigate the norms and values of PNS through a structured review. An archive of 397 documents was collected, including documents that contribute to the endeavour of ameliorating science advice practices from a PNS perspective. Action and structure-oriented viewpoints are used as complementing perspectives in the analysis of the ethos of PNS. From the action-perspective we study how prototypes of norms and values are reflected upon in negotiations of normative issues relating to science advice. From the structural perspective we study how interrelated prototypes of norms and values are presupposed in prescriptions, proscriptions, and goals for science advice practices. Through this analysis we identify a plurality of interrelated prototypes of norms and values. Finally, we propose an acronym that integrates the analysed plurality of norms and values. As a mnemonic and communicative devise we call this ethos TRUST (Transparency, Robustness, Uncertainty management, Sustainability, and Transdisciplinarity) and propose TRUST as a nexus for future reflective negotiations of ambivalences in post-normal practices of science advice.

1. Introduction

Public safety, credibility of science advice, and goals and conditions of science practices, are just a few examples of what is at stake in the debate over norms and values of science. Any attempt to discuss the ethos of science is immediately situated in a complex and multifaceted debate. This paper is a part of a larger project on the norms and values of Post-Normal Science (PNS), and it elaborates on an initial description of the ethos of PNS formulated by Kønig (2013). The objective of this report is to portray a prototypical structure of norms and values, and we propose that this structure may serve as a nexus for future reflective negotiations of normative trade-offs in practices of science advice striving to implement the concept of PNS.

PNS was developed in the mid 1980s by Silvio O. Funtowicz and Jerome R. Ravetz who portrayed three different problem-solving strategies in risk assessment: applied science, professional consultancy, and PNS (1991, 1992, 1993; 1985). Each strategy fits different types of problematic situations. When both system uncertainties and decision stakes are low, applied science can continue its routine work within a disciplinary matrix of shared assumptions (Kuhn, 1996). Applied science is what comes closest to core science. However, normal science puzzle solving is inadequate when stakes or uncertainties rise to a medium level. Professional consultancy is more appropriate under these conditions. Professional consultancy, the typical strategy of senior engineers and surgeons, involves uncertainty and stakeholder awareness, along with skills and

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judgement in the problem solving approach. Both applied science and professional consultancy are inadequate when facing post-normal conditions characterised by irreducible complexity, deep uncertainties, a plurality of legitimate perspectives, value dissent, high stakes, and decision urgency (Funtowicz & Ravetz, 1991, 1992, 1993).

The post-normal methodology for a more robust 'science for policy' involves an extended peer community, both internally and externally. The internal extension involves expert elicitations where multiple disciplines work together on the assessment of quality and uncertainty. The external extension is the inclusion of representatives from all relevant stakeholders in the processes of problem framing, choices of indicators, and quality assurance. The extended peer community involves broader notions of facts, including for example leaked documents, local experiences, and information provided by investigative journalists (Funtowicz & Ravetz, 1992, 1993). These 'extended facts' are highly relevant for the problem framing process and the choices of indicators. The extended peer community safeguards against pitfalls and errors such as tunnel vision (a to narrow framing of the problem to make it fit a single disciplinary approach) and Type III errors (a problem framing error leading to the assessment of the wrong problem).

The management of uncertainty involves a framework for the assessment and communication of uncertainty including not only technical and methodological uncertainties but also qualitative uncertainties such as epistemological and ethical uncertainties. The acknowledgement and management of plural legitimate perspectives involves among other things a framework for making it possible for stakeholders to engage in constructive and open dialogue cultivating mutual learning despite different disciplinary backgrounds, conflicting interests, and value disputes.

The goal of the post-normal methodology is to produce socially and technically robust information fit for sustainable decision-making. Avoiding pitfalls and errors such as tunnel vision and misapplication improves robustness and thus the quality of the policy advice.

When comparing "normal" to "post-normal" one can find plural and interesting differences, however for our purpose here we shall only point out one important difference, namely their contrasting conceptions of the very objective of science. In normal science the goal is knowledge, and quality equals certainty, not robustness. In PNS quality is the goal, not knowledge. Quality is not only about the product but also includes process, people, and purposes when information is to be fit for sustainable decision-making (Funtowicz & Ravetz, 1993). Due to these contrasts, one might be mislead to think that 'normal' and 'post-normal' are in contradiction. However, different tools are fit for different tasks. Post-normal does not substitute but complements normal science. PNS still needs normal science as long as normal science is not applied outside its jurisdiction of problems with low stakes and low uncertainties. Nevertheless, there are tensions between normal and PNS. One source of tension is the challenge of agreeing on the nature of the problem situation. There can of course be dissent when it comes to assessing the degree of stakes and uncertainties of a given issue. We shall return to the tensions between normal and PNS when analysing the ethos of PNS (Section 5) and when reflecting upon possible normative trade-offs and ambivalences in practices of science advice striving to implement the PNS framework (Section 7).

Despite the possible tensions between normal and post-normal, it should still be clear that the norms and values of the different problem solving strategies depend on and are developed under different conditions of problem solving. We elaborate further on this context dependency of norms and values in Section 2. Here, we simply wish to stretch that the situated character of norms and values serves as a premise when we analyse the ethos of PNS.

Our analysis of norms and values of PNS is inspired by Robert K. Merton's notion of an ethos of science (Merton, 1973). However, Merton's structural functionalistic approach to the sociology of science and his analysis of its norms have received substantial critique. Hence, before we describe the norms and values of PNS, the Mertonian legacy needs clarification.

2. The Mertonian legacy

Robert K. Merton's acronym CUDOS stands for: Communalism (a scientist ought to make knowledge accessible to other scientists, as knowledge is common ownership), Universalism (scientists ought to assess knowledge claims based on pre-established impersonal criteria), Disinterestedness (a scientist may not hold conflicts of interest that can corrupt the research results) and Organized Scepticism (scientists ought to conduct organised quality control of knowledge claims.) (Merton, 1973).

It has become common to refer to CUDOS as "Merton's norms". However, Hans Radder (2010) has reinterpreted CUDOS as values that are institutionalized through more specific norms described in codes of conduct. Merton himself described CUDOS as four sets of norms and values (Merton, 1973). But, as Radar rightly points out, one can find examples where Merton uses "mores", "imperatives", "norms" and "values" without clear criteria for the distinctions (Radder, 2010, p. 242).

We claim, like Merton, that an ethos of science involves both norms and values. We interpret norms and values as complementary when analysing how normative structures are presupposed in prescriptions, proscriptions, and goals of science advice. Norms relate to values as means to ends. Values are ends in view, something important to strive for and work towards, while norms are expressed in pre- and proscriptions of "how" when working towards certain ends in view. However, the relation between norms and values are dynamic. If one poses the question, is "universalism" a norm or a value? The short answer is, it depends on the framing of means and ends. If we interpret "universalism" as a means towards the end of extending certified knowledge, then "universalism" is a norm. However, if we zoom in on the activity of peer review, then the end in view of peer review is to provide impersonal quality control. From this perspective "universalism" is the underlying value of peer review.

Drawing on prototype theory (Lakoff, 1987; Rosch, 1978) we assume that categorisations of norms, values, actions, and goals are not any different from other categorisations. In natural language, categories are not sets or defined through a checklist of necessary and sufficient conditions of category membership. On the contrary, categories are defined through their distinctive and oppositional relations to other categories and in terms of typical examples. Prototypes are relationally defined exemplars. The prototype of 'mother' is a female, who has given birth to and nurtured her child. Categories such as stepmother, biological mother, and surrogate mother are distinctions introduced to mark a variation from the prototypical concept of mother (Lakoff, 1987). Inspired by this perspective we interpret norms as expressed in pre- or proscriptions of prototypical actions. In addition, we interpret values as prototypical ends in view, best examples of something important and desirable. This approach to norms and values is in clear contrast to Merton's notion of norms and values as sets.

The norm of truthfulness can serve as an illustration of the prototype approach. "One should not lie" is an example of what we mean by a prototypical norm. White lies and social lies are distinctions marking a deviation from the prototypical action of lying, namely "a false utterance which is intentionally deceptive" (Bloomquist, 2010, p. 1597). In addition, some norms and values are exemplary within a certain practice, meaning that these norms and values are the typical examples given when proper conduct is the topic of conversation. Thus, when we refer to prototypical norms and values we presuppose this double meaning of being defined through prototypes of actions and goals and being among the exemplars of norms and values reflected upon within a practice.

When people are to give an initial account of what is wrong in certain science-society issues they tend to draw on what they consider to be best examples of relevant and important norms and values.

Why is the commodification of research and the following secrecy between colleagues in academia a problem? Communalism and organised scepticism are violated. Secrecy makes it hard to share, criticise, and develop each other's ideas.

Why do we condemn that "*scientists are required to accept the judgements of scientifically incompetent political leaders concerning matters of science*" (Merton, 1938, p. 327)? Politicisation of science violates disinterestedness, universalism, and organised scepticism.

CUDOS targets prototypes of actions and goals. For example, disinterestedness as a value conveys the goal of impartiality and as a norm it disapproves of the prototypical action: A scientist consciously holds a hidden interest. This interest is likely to corrupt the research results. In other words, there is a clear conflict of interest between personal winnings and the common goal of the scientific community. However, conflicts of interest can vary in degrees. Distinctions can be introduced whenever one wishes to indicate deviations from the prototypical violation of disinterestedness. For example, one could distinguish between economically-disinterestedness and recognition-disinterestedness, or one can even be "in disguise" politically-disinterested like a stealth-issue advocate (Pielke, 2007).

Merton's claim, that CUDOS described the binding norms of scientists, has been the target of a massive critique, and we agree with several points of this criticism: CUDOS is an incomplete account of science practice (Mulkay, 1976). There often is a difference between what scientists say they do and what they actually do in practice (Barnes & Dolby, 1970). Bias and value commitments are present in the practice of science, and even more so in scientific policy advice (Jasanoff, 1990a). Peer-review is not fail-safe (Benos et al., 2007; Jasanoff, 1990b; Mulligan, 2005). Falsification, fabrication, plagiarism, and other types of scientific misconduct do, all too often, slip through the quality control mechanisms of science (Jasanoff, 1990b; Lerner, 2003). Old boyism and pal review are real threats to the credibility of the peer review system (Benos et al., 2007). There is a tendency to be more sceptical towards truth claims not consistent with certain assumptions while being less critical towards claims coherent with these assumptions (Barnes & Dolby, 1970). The Matthew and the Matilda effect are still haunting award and citation practices in contemporary science practices. The Matthew effect (over-recognition of scientists at the top) and the Matilda effect (devaluation of women's scientific accomplishments) do violate the norm of universalism (Lincoln, Pincus, Koster, & Leboy, 2012; Merton, 1968; Rossiter, 1993). CUDOS is not an adequate description of the norms and values binding scientists (Jasanoff, 1987, 1990b). Furthermore, CUDOS can be used strategically in boundary work to extend the authority, resources, and power of scientists (Gieryn, 1983, 1999).

Despite the massive critique of CUDOS, these norms and values are a returning topic when science-society issues are discussed (Anderson, Ronning, De Vries, & Martinson, 2010; Knuuttila, 2012; Mitroff, 1974; Radder, 2010; Vermeir, 2013; Ziman, 2002). We argue that CUDOS can be regarded as a nexus in the debate over norms and values of academic science not because of its ability to describe science practice, but because these norms and values are prototypes when it comes to issues of commercialisation and politicisation of academic science.

Analysing CUDOS as prototypes implies that they cannot be reduced to "a pure science ideology" (Mulkay, 1976). We agree that scientists can be interpreted as an interest group, and CUDOS is part of a "vocabulary of justification" when these interests are defended. But CUDOS are also brought into play in genuine attempts to define, negotiate, and propose solutions to different problematic situations arising in relation to e.g. politicisation and commercialisation of academic research.

According to the prototype view of norms and values, the ethos of science is both a presupposed normative structure and a topic for continual negotiations. This interpretation involves two complementing perspectives. First, an action oriented perspective that poses the question: what are the agents doing when they reflect upon norms and values? Second, a structure oriented perspective that poses the question: What interrelations of norms and values are presupposed in pre- and proscriptions of science advice?

When we describe how agents are negotiating the meaning and relevance of prototypical norms and values in relation to specific issues we do so from the action perspective. When we refer to the ethos of science from the action-perspective it is a structure in the process of being maintained and slightly modified by negotiating agents.

When we refer to the ethos of science from the structural-perspective, the ethos of science is a presupposed normative structure expressed in pre- and proscriptions of a specific practice. An example may serve to illustrate the structural perspective. If we consider the practice of driving and then imagine that two cars are colliding in the middle of an intersection. Since no one was hurt, the two drivers engage in a conversation over responsibility. One driver says to the other "It was you, not me, who crossed the red light". What structures of norms and values are presupposed in order for the drivers to understand this utterance as a normative statement? When trying to answer this question one may point to some obvious rules of the practice, e.g. the prescription, "a red light means 'stop"' and the proscription, "if the light is red you may not cross the stop line." In order to make sense of the presupposed normative structure of these specific rules one may ask what is the underlying value of traffic rules? Most people, if asked, would point to the safety of traffic. Further, a means to safe driving is responsible drivers. Being a responsible driver involves among other things not breaking the rules of the roads, show courtesy towards other road users, being aware, and paying attention to the surroundings of one's vehicle. Thus, safety, responsibility, awareness, attentiveness, and courtesy are some of the norms and values that are presupposed when making sense of the above normative utterance. These norms and values are defined in relation to each other. When characterising the relations one is describing the normative structure. The example illustrates that responsible driving is a means to the end in view of safety. Another example could be dichotomies where the oppositional relations are conceptualised in terms of positives versus negatives, such as responsible versus irresponsible, and safe versus unsafe. An important point is that one cannot describe normative structures without explaining how the norms and values are anchored in the specific practice. In the above example this implies that one needs to answer what responsibility and safety mean in the practice of driving. The anchoring of norms and values are done through best examples within the practice. Safety is the end in view of a moving traffic without anyone getting hurt.

When we analyse the ethos of PNS from the structural perspective the exemplary pre- and proscriptions of science advice are what comes closest to the rules of the road. The above example of a means to end relation between responsibility and safety illustrates what we describe as an underlying prototypical structure. The norms and values of awareness, attentiveness, courtesy, responsibility, and safety are good candidates for prototypes within the practice of driving and are likely to be articulated in legislative documents and information materials on the rules of the road. In addition, the action perspective from which we study reflective negotiations of norms and values would be analogue to politicians engaging in negotiations over norms and values of traffic e.g. in relation to a possible change to a specific road rule.

The objective of our study is to analyse norms and values in documents that reflect on and strive to ameliorate science advice practices from a PNS perspective. Through this analysis we portray the ethos of PNS as a prototypical structure of norms and values. We interpret such a prototypical structure as a potential for normative meaning making. We assume that such a potential is likely to be brought into play in practices of science advice that strive to implement the concept of PNS. However, we do not claim that the ethos of PNS will be the only norms and values that are brought into play in these practices, on the contrary the ethos of PNS is better understood as a potential or a tool for normative meaning making. Such a tool can be put to use for example in negotiations over best practices of science advice.

In the following section we present the reasoning behind our choice of method together with the search strategy and criteria for inclusion and exclusion of documents.

3. The PNS archive

In conducting a document analysis, one may criticise this method for missing the actual practices of post-normal science advice. However, a fieldwork study of post-normal policy advice practices would not give us what we seek. Many studies of PNS in practice encounters the problem that the practice under study is in the process of implementing the concept of PNS and thus cannot be interpreted as a full blown exemplar of PNS in practice, but rather as a hybrid of both normal and post-normal practices (Krauss & Von Storch, 2012; A. Petersen, Cath, Hage, Kunseler, & Van der Sluijs, 2011; Swedeen, 2006). Hence, if we were to undertake such a study we would most likely end up with a hybrid of normal and post-normal norms and values. We argue that a document analysis is a better tool for the task, because the norms and values of PNS are both reflected upon and most clearly expressed in PNS documents striving to ameliorate the practice of science advice.

For our analysis we have collected an archive of 397 PNS documents. The following criterion has been used for the inclusion and exclusion of documents: *A document should contribute to the normative endeavour of ameliorating practices of science advice from a PNS perspective*. Journal articles, academic books and chapters, guidance reports, PhD-thesis, newspaper and magazine articles have been included if they satisfied the above criterion and were written in English. All other types of documents, such as conference reports and abstracts, web pages, blogs, and book reviews have been excluded.

Based on a degree of relevance the archive was categorised into three overall groups of documents: primary (of highest relevance), secondary (of direct relevance), and tertiary documents (of indirect relevance). The degree of relevance of each document was assessed based on the reading of titles, abstracts, introductions, keywords, and where necessary conclusions and discussions.

Primary documents are of two kinds: a) Documents which purpose is to guide the conduct of science advice and which is supposedly used in the practice it seeks to guide. Examples of these documents are the guidance reports targeting the

activities of the Netherlands Environmental Assessment Agency (Hage & Leroy, 2007; Van der Sluijs et al., 2003). b) Academic publications of Funtowicz and Ravetz and their co-authors. These documents are regarded as highly relevant since they have been instrumental in developing the concept of PNS. We do not include publications prior to 1985, and thus we exclude interesting background publications like *Scientific Knowledge and its Social Problems* (Ravetz, 1971). However, our focus is on PNS and its origin is tracked back to the mid 1980s (Ravetz & Funtowicz, 1985).

Secondary documents are all other academic publications that can be categorised as directly contributing to the improvement of science advice practices from a PNS perspective.

Tertiary documents target other practices, but are indirectly relevant for science advice practices. For example documents that strive to ameliorate education from a post-normal perspective (Barwell, 2013; Colucci-Gray, Perazzone, Dodman, & Camino, 2013). These documents can be interpreted as indirect contributions to the amelioration of science advice practices, because a post-normal education would be instrumental in providing better-equipped publics, scientific advisors, and decisions-makers for the challenges of our near future (See also Hiis Hauge and Barwell's discussion on the role of critical mathematics education, this issue.).

We combined two search methods, citation search and criterion driven search, and used a mixed method sampling in order to improve both breadth and depth of information in our sample (Teddlie & Yu, 2007).

Due to the inter- and transdisciplinary nature of the concept of PNS, we selected databases that include a variety of different disciplines, e.g., cultural, social, economic, and natural sciences: "Web of science", "Scopus", "EBSCO Host", "ScienceDirect", "SAGE Journals", and "Google scholar". They were searched with different combinations of the following search words: Primary search words: "post-normal science", "postnormal science", "postnormal times". Secondary search words: "science for policy", "science advice", "policy advice", "uncertainty assessment", "quality assurance", and "participation". Where possible the fields of TITLE-ABS-KEY were searched, however, databases like Google scholar and Web of science did not allow for these types of search, hence we limited the search results by searching TITLE or TOPIC.

With regards to the depth of information, we started our citation search at the website (www.nusap.net). References of the article (Funtowicz & Ravetz, 2008) let us to this website, maintained by Jeroen P. van der Sluijs, one of the leading scholars of PNS, it presents work related to PNS and methods of uncertainty and quality assessments.

We have assessed the relevance of all documents based on our inclusion criterion by reading titles, abstracts, keywords, lists of content, and introductions. A reference management system (www.zotero.org) was used to build the digital archive and handle de-duplications. Books, book chapters, and journal articles not previously digitalised have been scanned and optical character recognition (OCR) has been used in order to make these texts searchable.

4. Analytical strategy

The analytical coding of the PNS archive has been conducted through several iterations of using the action and the structure perspective (see Section 2). From the action perspective we posed the following analytical questions: 1) what are the prototypes of norms and values explicitly reflected upon and negotiated within the PNS archive? How are norms and values defined and reinterpreted from a post-normal perspective? From the structural perspective we posed the questions. 1) How are the prototypical norms and values we identify interrelated? 2) How are the prototypical structures of norms and values presupposed in exemplary pre- and proscriptions of science advice?

One encounters a plurality of normative expressions when identifying and analysing how norms and values are articulated. However, the smallest unit of our analysis is not any normative utterance. Because of the prototype approach we are only concerned with exemplary pre- and proscriptions. In order for a chunk of normative utterances to count as an exemplary pre- or proscription, it shall have been given a name within the PNS archive. 'Type III errors' and 'tunnel vision' can serve as examples of expressions of exemplary proscriptions that have been given a name. The notational system NUSAP can serve as an example of an exemplary chunk of prescriptions. Thus, we searched the PNS archive to identify prototypes of norms and values and exemplary pre- and proscriptions.

The immediate challenge to a digital search is that any search criteria will be a string of characters without meaning. Therefore, we have combined reading and coding with digital content searching. The approach has been iterative and incremental. To give an example, if one reads documents like (Funtowicz & Ravetz, 1990, 1991, 1992, 1994b) one will encounter the norm of democratization of scientific expertise. But one still does not know whether or not this norm can be regarded as a prototype within PNS. When searching the archive for the truncated string "democrati*" the result is 1116 instances in 207 documents. This result tells us almost nothing about the status of the norm within the archive, because one does not yet know why the string is there. An individual search hit could for example be part of an argument against the norm or it could be part of a title in the references of the document. However, the instances of search results are indexes that serve as entry points for further reading and annotation. Hence going through these 1116 instances (reading the immediate paragraph surrounding the string) allows for a systematic identification and annotation of all paragraphs that explicitly reflect upon or name democratization of scientific expertise. Further, if a paragraph is deemed relevant this counts as a reason for reading the whole text.

When reading the text one might encounter other norms and values, and thus adding to the list of words that again are translated into search strings and used as new indexes in yet another iteration of searching, reading, and coding. The criterion for ending this process has been saturation, namely when no new prototypical norms, values, exemplary prescriptions, or proscriptions were identified.

We have conducted a thematic coding of the documents in the PNS archive, based on the open question 'what is this article about and what is the overall theme for this topic?' The result was a huge set of themes. From this set of themes we have selected the once that can be regarded as a part of or directly relevant to the practice of science advice. The selected themes are: Goals and conditions of science advice, problem framing, uncertainty assessment and communication, interdisciplinary collaboration, stakeholder involvement, and participatory processes. Other themes such as policy dilemmas, the amelioration of science and engineering education, the design of governance regimes, mega-site management, implications of complexity to governance, the evolution of ecological economics, and many others are also present in the archive, but due to our focus on the improvement of science advice practices these other themes only serve as an interpretative background. Three primary or secondary documents have been selected from each of the above selected themes. These documents have been read and the norms, values, and names of exemplary pre- and proscriptions identified within these documents have been the starting point for the iterative and incremental process of identifying interrelated or co-occurring norms and values.

5. Analysis: the ethos of PNS

The following analysis is centred on the theme of goals and conditions of science advice since the norms and values encountered in relation to this theme are also found to serve as underlying norms and values of the remaining themes. Norms and values targeting the other themes are brought in when appropriate. The analysis is structured as follows: First, we give an interpretative overview of the prototypical normative structure that can be found in the PNS archive. We will comment upon just 18 selected norms and values, enough to get a concrete idea of the approach. Second, we analyse two examples of how different prototypes of norms and values are reflected upon and negotiated. These examples illustrate how the ethos of PNS can be interpreted as a structure in the process of being maintained and modified through negotiations of norms and values. Finally, we demonstrate how prototypical structures of norms and values are presupposed in exemplary pre- and proscriptions.

5.1. An interpretative overview

So what norms and values were identified as prototypes in the PNS archive? In total we identified 33 prototypical norms and values: 1. sustainability, 2. quality, 3. robustness, 4. inclusiveness, 5. democratization of expertise, 6. adaptability, 7. flexibility, 8. creativity, 9. holism, 10. pluralism, 11. integration, 12. awareness, 13. reflexivity, 14. humility, 15. relevance, 16. applicability, 17. precaution, 18. transparency, 19. traceability, 20. openness, 21. accountability, 22. intelligibility, 23. accessibility, 24. honesty, 25. trust, 26. responsibility, 27. safety, 28. dignity, 29. mutual understanding, 30. tolerance, 31. equity. 32. empowerment, and 33. Integrity. In the following we shall give an overall interpretation of the meaning and interrelation of the first 18 norms and values.

1. Sustainability is the core value of PNS, since the overall end in view of PNS is to contribute to more sustainable forms of development (Gallopín, Funtowicz, O'Connor, & Ravetz, 2001; Ravetz, 2006, p. 279). All the other norms and values listed above are developed through reflections on how practices of science advice (See also Pereira and Saltelli, this issue) can pursue this overall goal under highly challenging conditions of problem solving.

The conditions of science advice are characterised in the iconic phrase: " . . . *facts are uncertain, stakes high, value in dispute, and decisions urgent*" (Funtowicz & Ravetz, 1991, p. 138). However, more abstract portrays of the challenges of our times also inform us on the conditions of science advice (Funtowicz & Ravetz, 1993; Sardar, 2010). Further, these conditions of science for policy are taken into account and explicated in the domain defining assumptions of PNS. When science for policy is confronted with real world issues the domain of inquiry are emergent complex systems (Funtowicz & Ravetz, 1994a). These social and environmental systems include humans and thus reflexivity, consciousness, contradictions, morality, and continuous novelty. The properties of an emergent complex system cannot be adequately explained only with reference to its physical and biological subsystems and their interrelations. When dealing with emergent complex systems, imperfection, irreducible uncertainty, value commitments, unpredictability, and malevolence are facts of life.

Science advice practices working under the assumptions of normal science in a world of emergent complex systems are in need of amelioration. Even though normal and post-normal are not in contradiction the tension arises from the misapplication of normal science to complex policy relevant issues. Because of this tension, norms and values of PNS are often presented and defined in opposition to norms and values of normal science.

When working under post-normal conditions, quality is claimed to be a better end in view for science advice than the underlying value of normal science, truth (Funtowicz & Ravetz, 1994b, pp. 197–198).

2. Quality is fitness to function, and involves people, process, purpose, and product (Funtowicz & Ravetz, 1993, p. 744). The *purpose* of science advice information is to be fit for sustainable decision-making. From this purpose follows a quest for socially and technically robust information. Technically robust policy solutions are viable despite internal constrains and feasible despite variation in external constrains. The social robustness of policy solutions is their compatibility with a plurality of values among stakeholders (Benessia et al., 2016, p. 50). Robust information is safeguarded against errors and pitfalls and incorporate negotiations of value-laden assumptions. In addition, the robustness of information is intimately linked to the management of uncertainty.

3. *Robustness* is a prototypical value, when it comes to information as the *product* of science advice. However, when working under post-normal conditions social and technical robustness can only be provided with the inclusion of the right *people* (the extended peer community) and through the right kinds of quality assessment *processes* (extended peer review). The underlying norms of the extended peer community and extended peer review are 4. *inclusiveness* and 5. *democratization of scientific expertise* (Funtowicz & Ravetz, 1991, p. 151, 1992, p. 252; Funtowicz & Strand, 2011, p. 998). Thus, the four P's of quality are related to the norms and values of sustainability (purpose), robustness (product), inclusiveness (people) and democratization of expertise (process). From this initial analysis the contours of a prototypical structure are emerging: The norms of inclusiveness and democratization of expertise are means to the end of robustness. Robustness is a means to the end of quality. Quality is a means to the end of sustainability. However, inclusiveness and democratization of expertise are of course not the only means to the end in view of social and technical robustness.

6. *Adaptability* demands that science advice practices adapt to the post-normal conditions. These conditions (e.g. of uncertainty, ignorance, and unpredictability) are portrayed as "facts of life". Since everyone needs to adapt to "facts of life" this expression articulates the norm of adaptability.

> "One can see uncertainty as a mere fact of life, something that unavoidably plays a role in complex and politically sensitive topics. We accept the fact that uncertainty and dissent are not temporary but permanent, . . . " (Van der Sluijs, 2012, p. 187)

A part of the norm of adaptability is to acknowledge that uncertainties cannot be reduced and ought to be managed by adapting our tools of inquiry to the so-called "monsters of uncertainty" (Curry & Webster, 2011; Van der Sluijs, 2005). High uncertainty creates situations where categories, we normally regard as mutually exclusive, are conflated. Under post-normal conditions, dichotomies such as values versus facts, ignorance versus knowledge, and prediction versus speculation collapse into monsters of uncertainty. We ought to deal with the monsters of uncertainty, neither embrace them, nor exorcise them, or purify them, but adapt our tools and categories to them, that is adopting the so-called "monster assimilation" approach (Van der Sluijs, 2005). When adapting to the post-normal facts of life one needs to be flexible.

7. *Flexibility* means that one ought to be open towards variation, change, and surprises. When working within imperfection one ought to be flexible with regards to the vague nature of qualitative judgements (Van der Sluijs et al., 2003, p. 58). In addition, the norm operates in multidisciplinary work of scientific advice where one ought to be open towards other practices and perspectives. The norm of flexibility goes hand in hand with the norm of creativity.

8. *Creativity* has taken centre stage when striving to adapt to the post-normal facts of life (Sardar, 2010, p. 443; see also Arthur C. Petersen, 2014, p. 25; Hage & Leroy, 2008, p. 58). Creativity as a norm demands us to develop new ways of navigating under complexity and contradiction, envision alternative futures, new tools and solutions, being open towards new conceptualisations and ways of thinking, and last but not least it demands a willingness to learn from others and develop through deliberative processes (Montuori, 2011; Sardar, 2010).

9. *Holism* is another norm linked to the values of robustness and sustainability. The social, economic, and environmental pillars of sustainability point to a holistic approach. People, profit, and planet are all included as intertwined subsystems in emergent complex systems (Giampietro, 1999, p. 219; see also Gallopín et al., 2001, p. 223). In PNS, holism is not only a theory where parts are understood in terms of the wholes, but also a norm that is expressed in prescriptions such as.

> "It is better to get an approximate answer for the whole problem/issue, than a precise answer for an isolated component." (Gallopín et al., 2001, p. 228)

Holism is interlinked with the norms and values of pluralism and integration.

10. *Pluralism* as a norm demands that one acknowledge plural legitimate perspectives on real world issues. Plural legitimate perspectives are not only a fact of life but are also regarded as a resource for more social and technical robust solutions.

> "A plurality of perspectives is considered as enhancing both procedural legitimacy (through inclusiveness) and quality of knowledge (through extended peer review)." (Liberatore & Funtowicz, 2003, p. 149)

11. *Integration* means that one ought to integrate the plurality of legitimate perspectives. Holism, pluralism, and integration are interrelated with inclusiveness and democratization of expertise, since the goal of finding an approximate answer to the "whole issue" can only be obtained by taking part in a genuine democratic deliberation among representatives from all stakeholders of the issue. Only thus can one integrate the plural legitimate perspectives and put them to work for a more holistic approach to the issue.

12. *Awareness* is another prototypical norm within PNS that are called upon in the quest of adaptability (Ravetz, 2002, p. 262). When dealing with emergent complex systems, science advisors ought to be aware of their own ignorance, uncertainties, and value-laden assumptions along with the interaction of uncertainty and values.

Reflexivity prescribes that one turns something, which is normally not questioned, into a topic for further study and deliberation. Reflexivity is a means to raise awareness and promote mutual learning (Kovacic & Giampietro, 2015, p. 59).

14. *Humility* demands science advisors to be humble with regards to their powers of prediction and control when targeting real world issues. Awareness and reflexivity with regards to the limited powers of science promotes humility (Sardar, 2010, p. 437; Sardar & Ravetz, 1994, p. 563).

Reflexivity, awareness, and humility guide science advice towards adaptability. The values of adaptability and democratization of expertise are articulated and summarised in the phrase "*Working deliberately within imperfection*"

(Funtowicz, 2006, p. 140). Adaptability and democratization of expertise are means to the ends in view of *15. relevance* and *16. applicability*. The methodology of science advice needs to be both relevant and applicable to complex policy issues. The information of science advice needs to be socially and technically robust and a necessary (albeit not sufficient) requirement of robustness is relevance and applicability.

17. Precaution puts other types of questions in focus. In post-normal practices the questions of 'why' and 'how' are not so dominating as 'what about' and 'what if' questions (Ravetz, 1997; see also Marshall & Picou, 2008, p. 243). Indeed precaution is a prototype within PNS, so important that PNS is also named a precautionary science" (Ravetz, 2004). Precaution in action means being sensitive towards "early warnings". Reflective deliberations among stakeholders can both enhance sensitivity to and awareness of early warnings. The so called NIMBY (Not In My Back Yard) groups can be put to work for precaution, because "*Those whose lives and livelihood depend on the solution of the problems will have a keen awareness of how general principles are realized in their "back yards"*" (Funtowicz & Ravetz, 1991, p. 149). Thus, precaution is for example linked to the norms of inclusiveness, pluralism, and democratization of expertise.

18. Transparency is a prototypical value, since PNS is opposed to secrecy in science for policy. No steps relevant to the quality of the expert advice should be hidden from the public. All possible conflicts of interest, value-laden assumptions, and uncertainties should be brought out in the open (See for example: De Marchi & Ravetz, 1999, p. 755; Hauge, 2011, p. 179; Mayumi & Giampietro, 2006, p. 396).

The norms and values of inclusiveness, democratization of expertise, holism, awareness, humility, reflexivity, transparency, openness, and accountability all serve as means to the basic values of *honesty* and *trust* within the science-policy interface. *Trust* is not only an end in view. It is also a central part of the normative means (Healy, 1999, p. 660). Trust is what is needed in the extended peer community in order to have a constructive dialogue on the most pressing issues of our times.

Misapplications of normal science methodologies to complex policy relevant issues have resulted in a plurality of hazards and a growing public mistrust. Hence, a basic normative question underlying the ethos of PNS is: how can we regain the public trust, by cultivating a practice of science for policy that can, despite working under imperfection, provide *honest* advice useful for sustainable decision making? To regain the public trust, other norms, values, and practices of science for policy are needed. The ethos of PNS, as portrayed above, can be interpreted as the answer to this quest.

The prototypical structure consists of a plurality of means to end relations that again are conceptualised in oppositional relations of positives versus negatives (e.g. sustainable versus unsustainable; humility versus hubris; trust versus mistrust).

5.2. A prototypical structure up for negotiation

With the above interpretative overview of an emerging prototypical normative structure, we shall now turn to the action perspective and the analytical question: How are norms and values reinterpreted from a post-normal perspective? We shall see examples of how aspects of the ethos of science advice are negotiated within PNS through re-conceptualisations of norms and values of science advice. We provide two examples, namely the reinterpretation and negotiation of 'responsibility' and 'safety'. These norms and values are redefined in order to give them a new meaning that is in coherence with the norms and values of adaptability and honesty. When accepting uncertainty and unpredictability as facts of life, one can no longer conceptualise responsibility or safety in terms of control and predictability.

From a normal science perspective expert advisors are responsible to the public for informing about how to keep risks under control. Predictions of low probabilities of harm are used as guarantees of the public safety. However, when system uncertainty and decision stakes are high, responsibility cannot be understood in terms of predictability. Funtowicz and Strand redefine the meaning of 'responsibility'. They do so, by disentangling 'responsibility' from normal science values of certainty and predictability.

> "We shall argue that such alternatives call for a revision also in the concept of responsibility, decoupling it from the desire for control over the future . . . " (Funtowicz & Strand, 2011, p. 995)
>
> " . . . as a better standpoint than that of risk-based responsibility: commitment to the collective creation of knowledge about how to do good to preserve and extend humanity as a context to the prevention of evil." (Funtowicz & Strand, 2011, p. 998)

According to the above quotes the overall responsibility of science advice is nothing less than the survival and cultivation of humanity. However, when it comes to the responsibility for humankind it no longer makes sense to talk about remedy. This kind of responsibility needs to be distributed as a commitment among all stakeholders and thus democratised. From this somewhat abstract collective responsibility understood as "*a commitment to do good and preserve and extend humanity*" follows a practical responsibility for the quality of science advice and the advisory process. This redefinition of responsibility is in line with other uses of responsibility within the PNS archive. For example, responsibility is referred to as a capacity "*to listen to what others are saying*" (Frame & O'Connor, 2011, p. 4). In other words, a scientific policy advisor is responsible for a genuine reflective deliberation on how to preserve and extend humanity.

In the same manner 'safety' is redefined. It is claimed that 'safety' cannot be reduced to a question of acceptable risks. To understand problems of hazards in terms of probability and cost is simply the wrong way around safety (Ravetz, 2003).

> "For people to 'feel safe' it is not necessary to be convinced that a particular risk is at zero or negligible level. As we have seen, 'safety' is not a subjective equivalent of 'risk-free'. Rather, relating to the pragmatic and moral context of a hazard situation, it is about trust in those charged with protecting oneself and one's family." (Ravetz, 2003, p. 821)

Thus, 'safety' is redefined by disentangling the notion from predictability (risk-free) and in stead connecting it to trust as a more basic value of the human relations between protectors and protected.

These examples illustrate how the ethos of PNS is a structure in the process of being maintained and modified through negotiations of the meaning of prototypical norms and values.

5.3. Articulations of the ethos of PNS

We shall now switch back to the structural perspective, and give examples of how the ethos of PNS is presupposed. The exemplary pre- and proscriptions that we have identified within the whole PNS archive are the following. Prescriptions: Contradiction as heuristic for reflections on emergent complex systems, NUSAP as a notational system for better uncertainty and quality assessment. The so-called 'Knipselkrant' method (also known as the snowball method) for the identification of stakeholders, multi-criteria decision aid, mental modal mapping and value mapping. Proscriptions: Type III error (also known as misapplication of methods or "lamp-posting"), GIGO-science (Garbage In Garbage Out), scientific hubris (also known as the sin of "ignorance of ignorance" and the Cartesian dream of certainty), hyper-precision (also known as pseudo-precision), tunnel vision, hypocognition, complexity exclusion traps, pseudo-quantification, and pseudo-dialogue. We shall give two examples on how we analyse pre- and proscriptions. The examples are the proscription of Type III errors and the prescription of the Pedigree in the NUSAP scheme.

Quoting the work of Dunn (1997), the definition of Type III errors are found in the detailed guidance report striving to guide science advisors in the Netherlands Environmental Assessment Agency.

> "Type III error [. . .] Assessing or solving the wrong problem by incorrectly accepting the false meta-hypothesis that there is no difference between the boundaries of a problem, as defined by the analyst, and the actual boundaries of that problem" (Van der Sluijs et al., 2003, p. 63)

The above definition explicates what is to be avoided. In short, one shall not solve the wrong problem. Solving the wrong problem is of course irrelevant. Hence, the definition articulates the norm of relevance. In addition, the norm of applicability is articulated since solving the wrong problem is a special case of misapplication and thus a violation of applicability. Further, awareness and adaptability are articulated because the above acceptance of the "false meta-hypothesis" can be interpreted as a lack of awareness of one's own ignorance and hence also a violation of adaptability. A science advisor, who assumes that any policy relevant issue is highly complex involving irreducible uncertainties, ignorance, and unpredictability, would be hesitant to accept the above "false meta-hypothesis". This is one of the reasons why Type III errors are connected to a normal science approach.

> "Type III errors are a characteristic pitfall when the 'normal science' approach is deployed in post-normal situations." (Funtowicz & Ravetz, 2003, p. 6)

When analysing the presupposed norms and values of proscriptions it can be informing to look for the inversed prescription. The inversed prescription to the proscription of Type III errors can be found in the guidance report as "context validation":

> "Context validation thus is minimizing the probability that one overlooks something of relevance. It can be performed by a participatory bottom-up process eliciting from stakeholders those aspects considered relevant as well as rival hypotheses on underlying causal relations, and rival problem definitions and problem framings." (Van der Sluijs et al., 2003, p. 51)

In this prescription relevance is explicitly mentioned and the norm of pluralism is articulated by regarding "rival hypothesis" and "rival problem framings" as a resource for safeguarding against Type III errors. Furthermore, inclusiveness and democratization are articulated in "a participatory bottom-up process".

The NUSAP system is an exemplary chunk of prescriptions in the post-normal methodology. Numerical, Unit, Spread, Assessment, Pedigree is the notational scheme of qualifiers of quantities, proposed to improve the expression and analysis of quality and uncertainty in scientific policy advice (Funtowicz & Ravetz, 1990; Ravetz, 1990; Van der Sluijs, Risbey, & Ravetz, 2005). We shall not go into detail with all of the NUSAP system here. For our purpose, it is sufficient to look at pedigree assessments. A pedigree assessment evaluates the production process of quantitative information. The different phases of a pedigree can be e.g. empirical underpinnings, proxy, value-assumptions, method, and way of validation. Each phase comes in different modes. Modes are linguistic descriptions of judgements with regards to the strength of a phase. In expert elicitations, different experts give their qualitative judgement of different phases of pedigrees.

What norms and values are presupposed in the prescription that one ought to conduct a pedigree assessment? First, the norm of reflexivity is presupposed because when different experts give their qualitative judgements of the different phases of pedigrees it is very likely that they will not agree. Disagreement promotes deliberation and reflexivity (Craye, Funtowicz, & Van der Sluijs, 2005, p. 222).

Another norm articulated is awareness, since the very task of conducting a qualitative assessment of the production process of quantitative information raises awareness towards epistemological uncertainties and value-assumptions. In addition, the pedigree assessment allows other users of the quantitative information to trace the origin of certain quantitative statements. The norm of traceability is presupposed, and traceability is a means to the end of transparency. Pedigree assessments can: " . . . *increase the transparency of the scientific input in the policy context* . . . " (Craye et al., 2005, p. 224). The 'Pedigree' has become a warrant of transparency when the quality of models is judged: "*A model is said to be transparent if its pedigree is well documented* . . . " (Van der Sluijs et al., 2003, p. 63). Thus, pedigree assessments presuppose the norms and values of reflexivity, awareness, traceability, and transparency.

6. TRUST in science for policy

Mertons acronym CUDOS has to a wide extent served as a mnemonic and communicative device for the norms and values of normal science. Even though many other norms and values are present in normal science (e.g. rigor, originality, and predictability) CUDOS has served as a starting point for many normative negotiations within academic research. Inspired by Merton we shall seek to develop an alternative acronym. However, the challenge is that we have to find a way to comprise all 33 norms and values that we identified in Section 5, into a single word. Perhaps, a way forward is to find a word that conveys what is important. We suggest the acronym "TRUST". Whereas CUDOS (recognition) is what one achieves by complying with the norms and values of normal science, TRUST (the public trust in science advice) is what can be regained by the ethos of PNS. A part of the norm of adaptability is that one ought to manage uncertainty instead of sticking to the illusion that one can tame all uncertainty. Hence, if we adopt the word 'uncertainty management' we can let TRUST stand for (Transparency, Robustness, Uncertainty management, Sustainability, and Tolerance).

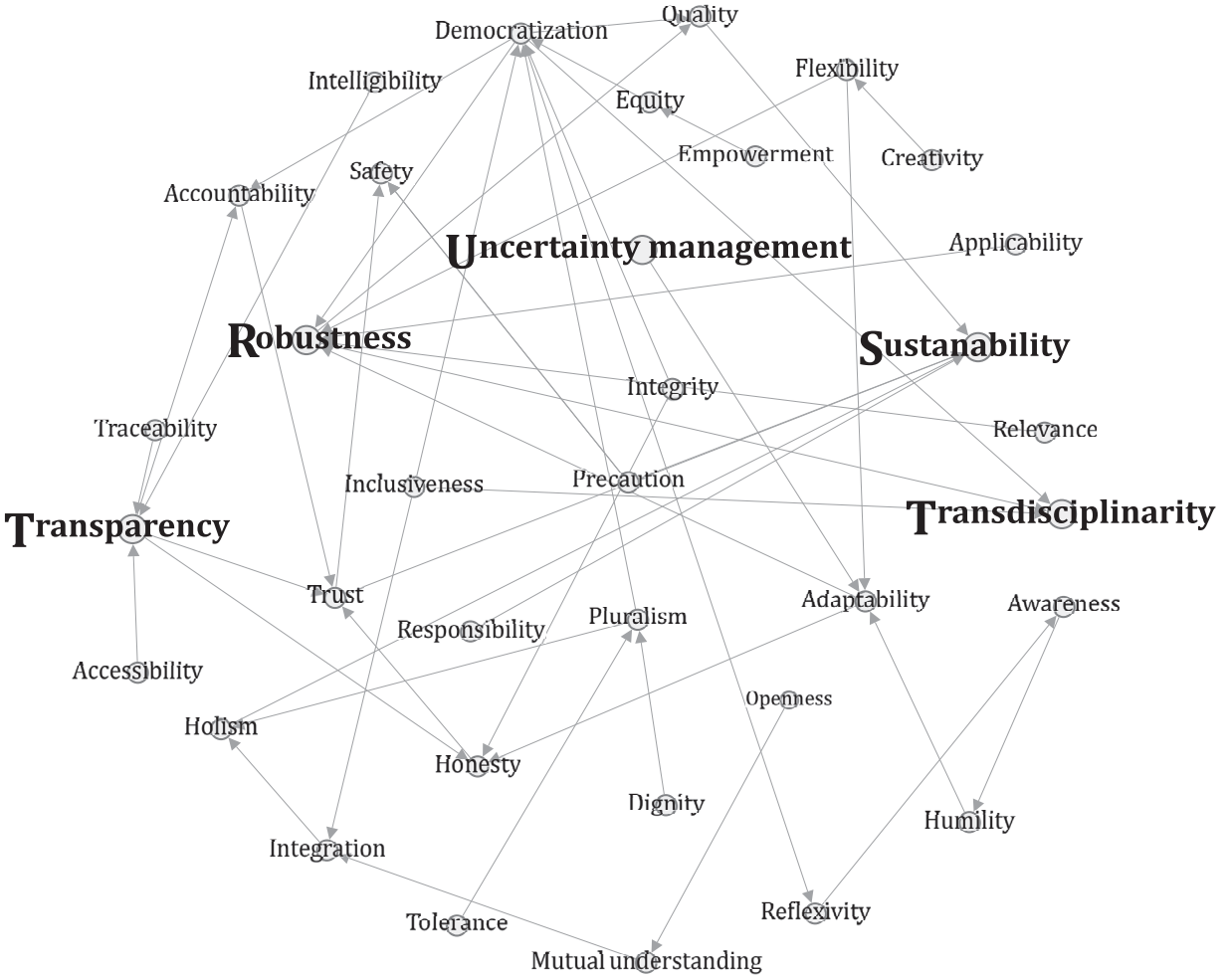

Fig. 1. The ethos of PNS.

Since the 33 norms and values are interlinked in a complex means end structure it should be possible to portray how TRUST is interlinked with all of the other norms and values of the ethos of PNS. To give an example, transparency is linked to traceability, accessibility, and intelligibility. Robustness is a direct or indirect end in view for most of the norms and values, and since sustainability is the overall goal of PNS this value is also interconnected with the whole prototypical structure. Uncertainty management is clearly linked to adaptability and thus indirectly linked to awareness and reflexivity (for a real world example of the importance of these norms, see Benessia and de Marchi, this issue) as was illustrated in how these norms and values were presupposed in the prescription of pedigree assessments. Tolerance is linked to pluralism, since tolerance is a means to an open dialogue and promotes mutual learning in extended peer review processes. In this sense all the five norms and values within TRUST is interconnected with the ethos of PNS. However, we consider 'transdisciplinarity' instead of tolerance, since transdisciplinarity has the communicative advantage that it appeals to a broader trend within different approaches of so-called clumsy solutions to complex policy relevant issues. But, then one might ask is PNS a transdisciplinary approach? There are interpretations within the PNS literature that subsume the post-normal methodology under the broader notion of transdisciplinarity (Frame & Brown, 2008, p. 226; Haag & Kaupenjohann, 2001, p. 45). Funtowicz and Ravetz characterise the relation between PNS and transdisciplinary research as " . . . *a complementary pair*." (Funtowicz & Ravetz, 2008, p. 361). Thus, it is with some caution that we suggest using 'transdisciplinarity' as a norm. According to a normative interpretation of transdisciplinarity one ought to contribute to the management and solution of real world issues. Facing real world issues most often involves dealing with emergent complex systems through a participatory problem solving strategy. Hence, transdisciplinarity is connected with the values of inclusiveness and democratization of expertise and will therefore serve as a better communicative device. Thus we suggest TRUST (Transparency, Robustness, Uncertainty management, Sustainability, and Transdisciplinarity) as a way to refer to the ethos of PNS. Fig. 1 illustrates how TRUST is interconnected with the rest of the norms and values of the ethos of PNS.

The norms and value in Fig. 1 are interconnected through a plurality of means to end relations. Each directed edge represents a means to end relation between nodes of norms and values, starting at the means and pointing to the ends. However, the graph should be interpreted with caution. It only shows aspects of the prototypical structure of the ethos of PNS, and many of the relations are in need of further studies. There are relations present in the graph that we have not commented on in the analysis and these relations may be regarded as hypothesis for future investigations. The graph serves a mnemonic and communicative purpose, showing how TRUST is interlinked with the other norms and values of the ethos of PNS.

7. Discussion and conclusion: TRUST a new nexus for reflexivity practices

We have argued that norms and values that are explicitly reflected upon and negotiated in the PNS archive are prototypes. This approach to the ethos of science allowed us to agree to many of the former criticisms of the Mertonian norms and values and to interpret CUDOS as a nexus for the continual reflection and negotiation of issues of commercialisation and politicisation of academic science.

Furthermore, we have outlined how the ethos of science can be analysed from two complementing perspectives. This analytical approach gave rise to a systematic study of the norms and values in the PNS archive. The ethos of PNS has been portrayed as a structure of prototypical norms and values. We have demonstrated how these norms and values are presupposed and articulated in post-normal prescriptions such as Pedigree assessments and in proscriptions exemplified by Type III errors.

We have portrayed the ethos of PNS as a structure of prototypical norms and values. When these norms and values are presented together under a common acronym, TRUST, they can serve as a reflective tool in practices of science advice striving to implement the concept of PNS. Thus, we suggest TRUST as a new nexus for reflective negotiations of normative issues and ambivalences in science advice practices.

Even if the different stakeholders can agree that they are confronted with a post-normal issue, the post-normal methodology will draw on normal science and thus both CUDOS and TRUST will be intertwined in this practice. Therefore, PNS needs to confront, deliberate, and balance norm conflicts such as disinterestedness versus accountability and transparency; universalism versus pluralism and democratization. We have proposed TRUST as a new nexus for such future negotiations of ambivalence in science advice practices striving to implement the concept of PNS. We propose TRUST, because it captures the ambition of developing a problem solving strategy within science for policy to show a way out of the credibility crisis and regain the public trust.

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Appendix A. Supplementary data

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