Environmental Science and Policy 141 (2023) 158–167

Contents lists available at ScienceDirect

Environmental Science and Policy

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

Post-normal science in practice: Reflections from scientific experts working on the European agri-food policy nexus

Kerry A. Waylen [a,*], Kirsty L. Blackstock [a], Keith B. Matthews [b], Alba Juarez-Bourke [a], Alice Hague [a], Doug Wardell-Johnson [b], Dave Miller [b], Zora Kovacic [c], Thomas Völker [c], Ângela Guimarães Pereira [d], Mario Giampietro [e,f]

[a] Social, Economic and Geographical Sciences Department, The James Hutton Institute, Aberdeen, Scotland AB15 8QH, UK
[b] Information and Computational Sciences Department, The James Hutton Institute, Aberdeen, Scotland AB15 8QH, UK
[c] University of Bergen, Centre for the Study of the Sciences and the Humanities, Parkveien 9, 5020 Bergen, Norway
[d] Joint Research Center of the European Commission, TP 361, 21027 Ispra, VA, Italy
[e] Institut de Ciència i Tecnologia Ambientals (ICTA), Universitat Autonoma de Barcelona, 08193 Barcelona, Spain
[f] Institució Catalana de Recerca i Estudis Avançats (ICREA), 08010 Barcelona, Spain

ARTICLE INFO

Keywords:
Transdisciplinarity
Nexus
Science-policy interface
Knowledge co-production
European policy
Scientific ethnography

ABSTRACT

Post-Normal Science (PNS) emphasises the need for scientists and policy-makers to iteratively co-analyse and learn together, as part of an extended peer community. However, the roles and implications for scientific experts when interacting with policy-makers are not well understood. Informed by insights from science and technology studies (STS) on modalities of interaction and the multiple potential roles of experts, we reflect on our experiences as scientific experts working on European agricultural policy within the interdisciplinary H2020 MAGIC project. We aimed to analyse and facilitate science-policy dialogue on a variety of European sustainability challenges. Whilst we achieved stimulating interactions on the nexus of issues associated with sustainable agriculture, our experiences did not fully match our deliberative vision. In part this was due to the varied constraints and reactions of policy-makers: many had limited remit for engagement, some expressed scientists should act as 'fact' providers in support of current tasks; others contested scientific analyses when these implied policy approaches were insufficient. Our own roles and reactions also varied across the scientific team and over time: from attempting to foster relationships, to emphasising our relevance to their tasks, or making stronger judgements. This dynamic mix was at times personally uncomfortable and challenging. Navigating such processes needs explicit reflection on the potentially plural roles expected of scientific and other experts working on and for sustainability. Meanwhile, the persistent expectations and institutional constraints that underlie and constrain science-policy interactions need more recognition, including by policy institutions themselves.

1. Introduction

This paper shares the experiences of researchers attempting to implement Post-Normal Science (PNS) to understand implications for achieving new forms of science-policy relationships for sustainability.

PNS reflects the view that facts and values are deeply entwined, especially when high decision stakes come together with uncertainty about the risks involved. This in turn means that science, politics and society cannot be treated as neatly demarcated entities. This has a number of implications, one of the most central being that assessments of the quality of decision-making, and the evidence used in decision-making processes, should engage a broad community of peers. For scientific experts, it requires them to see themselves as sharing and (co) creating knowledges in conjunction with policy-makers or other stakeholders. The principles of PNS thus include the recognition of the limits of scientific knowledge and the presence of uncertainty, decision-stakes

* Correspondence to: James Hutton Institute, Craigebuckler, Aberdeen, Scotland, AB15 8QH, UK.
E-mail addresses: Kerry.Waylen@hutton.ac.uk (K.A. Waylen), Kirsty.Blackstock@hutton.ac.uk (K.L. Blackstock), Keith.Matthews@hutton.ac.uk (K.B. Matthews), Alba.JuarezBourke@hutton.ac.uk (A. Juarez-Bourke), Alice.Hague@hutton.ac.uk (A. Hague), Doug.Wardell-Johnson@hutton.ac.uk (D. Wardell-Johnson), Dave.Miller@hutton.ac.uk (D. Miller), Zora.Kovacic@uib.no (Z. Kovacic), Thomas.Volker@uib.no (T. Völker), angela.pereira@ec.europa.eu (Â.G. Pereira), mario.giampietro@uab.cat (M. Giampietro).

https://doi.org/10.1016/j.envsci.2023.01.007
Received 8 December 2021; Received in revised form 24 December 2022; Accepted 11 January 2023
Available online 25 January 2023

and the influence of values on research; the desirability of including an extended peer community in decision-making that includes different types of knowledges; and promoting mutual learning amongst those holding different perspectives (Ravetz, 2004). Following these principles is believed especially important for complex, urgent and contested issues (Funtowicz and Ravetz, 1993).

These characteristics of urgency, complexity and contestation certainly characterise many challenges related to the climate and biodiversity crises, which are often called 'wicked problems' (Game et al., 2014). It is increasingly recognised that different environmental sectors or domains – such as water or terrestrial biodiversity management – are intertwined; and further, that societal interests and activities such as agriculture cannot be considered separate from the environment. Growing use of the term 'nexus' reflects the need to understand complex interconnected systems, though often without recognising the plural values and interests emphasised by PNS (Cairns and Krzywoszynska, 2016). Given the nature of these sustainability challenges, all the principles of PNS should be relevant: Ravetz (2018) specifically calls for 'transformative sustainability science' that reflects PNS principles. Other authors using similar labels of 'sustainability science' have added useful emphasis on the need for systems thinking (König, 2018), and the need for reflexivity (Popa et al., 2015).

Nearly three decades after the PNS concept was introduced, its principles have achieved influence, especially in the development of ecological economics (Funtowicz and Ravetz, 1991) and some discourse on the role of science in relation to policy (e.g. Gluckman, 2014). The spatial planning framework in South Africa is now claimed to be compatible with PNS (Buschke et al., 2019). However, as Turnpenny et al. (2011) observed, and continues to be the case, there have been few initiatives reported describing the application of PNS to tackle environmental challenges. A more recent review specifically of nexus management cases, similarly found a disappointing tendency to rely on traditional models of 'knowledge application', and few transdisciplinary processes (Urbinatti et al., 2020). Promisingly, Mason's (2021) recent paper on invasive species suggests PNS to be both relevant and feasible for developing debate around contested complex issues (Mason et al., 2021). Meanwhile, Dolter's (2021) account of deliberative modelling of energy generation gives useful insight into how these processes may evolve and adapt. So PNS is possible but rare. This is likely linked to the persistence of 'traditional' ideas of the role of science and its relationships with policy (Nutley et al., 2010), which limit opportunity to put PNS ideas into practice.

Beyond the above examples, there has generally been very little published on the detail of processes and experiences of individuals trying to implement PNS. This should be addressed, because enhancing reflexivity has been argued to be an important attribute for improving sustainability science (Popa et al., 2015). Without reflexivity, assumptions and habits may go unrecognised, potentially limiting the scope of learning and future achievements (Chilvers, 2013). Indeed, more detailed reflection on individual experiences would potentially benefit many science-policy interfaces and initiatives, not only those formally espousing PNS (e.g. Beck et al., 2014). For example, an exploration of an expert group within the European Commission by Décieux (2020) productively showed how the outputs of the group arose from the interactions of individuals reflecting a variety of stakes, interests and knowledges. More such insight into individual experiences could generate a deeper appreciation of the prospects and potential for PNS.

This paper addresses the need to better understand the roles of scientists attempting to achieve and embody new forms of science-policy relationships, in order to inform and improve future initiatives for sustainability science. To do so, we turn to the work of Turnhout (2019), to guide our exploration of the potential roles for individual scientists interacting with policy-makers.

1.1. Deepening the focus on scientific experts

In her work on the science-policy-society interface, Turnhout is interested in what she calls different modalities or repertoires of interactions that shape the ways in which scientists interact with other actors. According to the modality scientists draw on in any given situation, there are different roles that are available to them, different conceptions of the relation between science, policy and society and also different ways in which problems can be framed. A few other sources have reflected on the roles of scientists, notably Pielke's (2007) 4 potential modes of interaction for scientists, highlighting varying claims for objectivity, and a heuristic of 5 scientist roles by Wittmayer and Schäpke (2014) which highlights differing commitments and responsibilities as change agents, and the need for reflexivity. Turnhout's conceptualisation is consistent with these, and especially directs attention not only to the different roles that scholars assume in their interactions but also to the various ways in which scientists or academics are considered – or allowed – to act as experts. This depends not only on personal preferences but also, crucially, on the particular institutional and organisational context. In a similar manner, Smallman points to the broader cultural imaginative resources available to make sense of certain interactions or situations (Smallman, 2020).

Turnhout's modalities of interaction, shaping how different actors act and interact, can be summarised in terms of typology of 3 expert roles.[1].

1. Servicing, to provide facts to help solve problems already identified by policy-makers;
2. Advocacy, to argue for particular issue, problem or solution to be recognised;
3. Diversifying (called here brokerage), to facilitate inclusion of different views and knowledge.

Comparing these roles with the principles of PNS;

1. Servicing is linked to the ideas of 'normal' science and a linear understanding of the relation between science and policy, whereby the knowledge produced by scientific experts is presented as separate from politics and decision-making, and identified as "facts" and "evidence". It generally accepts and works within an established problem framing, without questioning it. It thus does not fit well with the principles of PNS, where science as well as policy are seen to be shaped by uncertainty, values and stakes.
2. Advocacy partially fits with PNS principles in that it reflects the ideas of acknowledging how values infuse knowledge and the scientific process, and critique of existing problem-framings is possible.
3. Brokerage may be the role that best fits with PNS ideas of how scientists should behave when interacting with policy makers, since it can imply an emphasis on plurality (as a means of acknowledging complexity) and the need to recognise and accommodate different values. It can enhance a group's recognition of different (potential) problem-framings.

This typology was introduced by Turnhout as a heuristic device to identify and navigate diverse possibilities for expert roles and modalities of interaction; not expecting individuals will conform strictly to one or other roles. This dynamic conception of expertise and expert roles builds

[1] We are aware that such a typology necessarily is a simplification and can be interpreted as encouraging an overly static representation of the multiple and shifting roles adopted and ascribed to researchers in their interactions in the science-policy-society interface. However, we argue that this typology with its sensibility towards modalities of interactions provides a good heuristic to systematically explore and reflect on our interactions with policy- and decision-makers.

on work on the "nature" of expertise by Science and Technology Studies (Collins and Evans, 2002; Jasanoff, 2003; Rip, 2003; Wynne, 2003). Scholars such as Wynne (2003, 1992) and Jasanoff (2004) argue that categories and classifications for demarcating experts from non-experts to ascribe (legitimate) expertise are co-produced, emerging through successive encounters between different experts and forms of expertise. Moreover, an essentialist notion of expertise as something that someone just 'has' independent of any particular situation is rejected, in favour of a position that it is "something acquired, and deployed, within particular historical, political, and cultural contexts." (Jasanoff, 2003, p. 393). This does not imply doing away with the distinction between experts and others, but directs attention to the processes by which these distinctions – and the different repertoires in Turnhout's words - become stabilised, rehearsed and also contested. Drawing on this literature we are therefore explicitly interested in how the different modalities and scientific expert roles evolve and change over time.

In this paper we reflect on 4 years of our evolving expert roles in the interdisciplinary H2020 'MAGIC' project,[2] that ran 2016–2020. The MAGIC project aimed to work closely with policy-makers, and to prompt, inform or inspire ideas about future policy change for sustainability. We focus here on interactions related to European agricultural policy. We ask:

1. What roles did MAGIC scientific experts expect to play when interacting with policy-makers?
2. What roles did these experts play in practice, and why?
3. What are the implications for the future development of PNS for sustainability?

We first describe more about the project and the academic experts within it, and the data we draw on here. To answer the first two research questions we then report how expert roles were anticipated and played out in practice. We then discuss implications for PNS and sustainability science in the final section of this paper, addressing the third research question.

2. Background - the MAGIC project and its experts

MAGIC was a large multi-partner Horizon2020 project that aimed to analyse and inform governance of the water-energy-food-environment (WEFE) nexus in Europe.

The MAGIC project was strongly interdisciplinary. Some of the scientists had previously collaborated, notably in a previous European-funded project[3] that involved many of the same principal investigators with expertise in data science and societal metabolism accounting, together with some experts in science and technology studies (STS), sociology and stakeholder engagement. MAGIC adjusted and expanded this team to give more capability in the social sciences, and in particular qualitative analysis of themes or narratives to contextualise and shape salient applications of the social metabolism approach. Both the quantitative and qualitative analyses were to be combined in an iterative process called 'Quantitative Story Telling' (QST). This process built on prior projects' methodological developments, and experience of work on science-policy interfaces (e.g. Matthews et al., 2011). It aimed to reflect a post-normal science ethos (Ravetz, 2004), going beyond interdisciplinarity to achieve transdisciplinarity, by iteratively involving stakeholders who would participate in and shape the research. For more detail on the MAGIC methodology see Matthews et al. (2021) and Blackstock et al., 2023.

Within the consortium there was a mix of academic disciplinary expertises; the societal metabolism analysis was implemented by data scientists, but called on other experts e.g. in ecology or physics; whilst the policy analysis was led by sociologists and other social scientists, using document and interview analysis. Many of the staff had mixed disciplinary backgrounds, e.g. geographers who now lead quantitative spatial policy analyses, ecologists who now analyse environmental governance challenges. Regardless of disciplinary background, many of the senior researchers describe themselves as working on or favouring systems perspectives and analyses. Some individuals might normally call themselves 'researchers' or 'analysts' instead of or as well as 'scientists' but all were employed by academic organisations, so all the individuals working on MAGIC are collectively referred to as 'scientific experts'. Expertise that is not strictly or solely academic was also needed; knowledge of EU institutions and processes, skills in data interpretation and visualisation, stakeholder recruitment, engagement and communication skills, expertise in team-working, and in workshop or event co-ordination. Many individuals within the team possessed multiple sources of expertise e.g. in part or all of the QST methodology, knowledge of datasets, experience in policy liaison in Europe or with national governments.

Stakeholder analysis was used to understand and differentiate different teams' and individuals' policy roles, though this was not explicitly discussed in terms of their varied expertise, a point we return to in the discussion. What we refer to in this paper as 'policy-makers' is a diverse set of individuals working in policy institutions, with differing interconnected roles, interests and agencies (Hodson et al., 2022). We were aware that the Joint Research Centre (JRC), the European Commission's science and knowledge service have PNS expertise – and were members of MAGIC – but we did not expect explicit awareness of this concept beyond JRC. European institutions have long endorsed evidence-based policy-making (e.g. European Commission, 2001) and so we expected policy-makers to have some familiarity with and support for the concept of liaising with scientific experts. However, rationales and recommendations for using science in European policy processes have often emphasised a 'strict separation' of science and policy, which does not well fit with PNS principles and modes of working (Saltelli and Giampietro, 2017), so we did not expect widespread familiarity with PNS.

The experiences described in this paper come from a strand of work concerned with the role of the EU Common Agricultural Policy (CAP) in influencing the sustainability of agricultural systems. This work was carried out in 2 iterative cycles of QST. In the first cycle, spanning 2016–2018, agriculture was part of an analysis encompassing a broader mix of sustainability-related policies: this highlighted agricultural policy's influence over natural resource flows. Additionally, around this time there was a vocal debate over the future of the CAP post-2020. There were calls for CAP to more strongly support environment policies and sustainability goals (e.g. Hart and Bas-Defossez, 2018), and proposals for agricultural policy to be part of broader 'Farm-to-Fork' i.e. food systems framing, as part of the European Green Deal.[4] We hoped this meant that new analyses of agricultural systems, such as ours, would be topical and timely. However, we did not know if the context would promote more interest in our work, or conversely if some policy-makers might be more cautious about opening up to new perspectives such as ours.

As a result, our second QST cycle, spanning 2019–2020, more strongly focused on agriculture. In both cycles, we analysed narratives

[2] The H2020 MAGIC project (Moving Towards Adaptive Governance in Complexity: Informing Nexus Security) is described and reported at https://cordis.europa.eu/project/id/689669

[3] The main predecessor to MAGIC is the FP7 SMILE project (Synergies in multiscale interlinkages of ecosocial systems): it is described at https://cordis.europa.eu/project/id/217213/

[4] A useful summary of the Green Deal programme as it was originally conceptualised in 2019, is provided by the European Parliamentary Research Service https://epthinktank.eu/2019/12/06/european-green-deal/ The evolving programme and specific actions since then are presented at https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

or themes associated with discourse on CAP policy. These informed quantitative analyses using 'societal metabolism accounting' methods (Giampietro and Mayumi, 2000), which highlight the funds and flows of materials and other societal resources associated with complex societal processes such as agricultural production. These analyses showed that many agricultural processes are associated with high flows of resources (e.g. water extraction, pollution loading), often placing unsustainable pressures on natural systems – presented in Matthews et al. (2021). Finally, we shared and discussed these qualitative and quantitative data with policy-makers.

The Supplementary material shows all the activities in the process of analysis and engagement across both QST cycles, focusing on the main meetings and events where academic experts working on MAGIC interacted with each other and/or with policy-makers. The total number of these science-policy mixed interactions was 16, whilst the total number of meetings involving academics working under MAGIC was 35 – of these the majority (24) involved scientists from different disciplines.

Our primary target for engagement were staff within the European Commission, as the Commission has responsibility for proposing new or updated laws and policies, and for monitoring their implementation. Individuals within the Commission have roles that vary greatly according to seniority, Directorate General (DG) and Unit; we initially targeted those working on agricultural policy analysis and integration with other sustainability policy goals. To discuss the material resulting from the first QST cycle we therefore organised a meeting held within DG Agriculture in October 2018. This reflected the focus of our analyses; and we were mindful that opening up can be encouraged in a 'safe space' (Pereira et al., 2015) away from other interests and Directorates. However, as this strategy did not feel entirely satisfactory to us, later in the project our engagement strategy broadened. To discuss the material generated in the second cycle of QST, we still sought to engage with those originally engaged in the first QST cycle, but also with policy-makers in other roles. The focal events resulting from this strategy were: a November 2019 event that mixed staff from several DGs including DG Agri in a neutral location; a January 2020 breakfast event for politicians and their staff at the European Parliament, which shares the power to adopt and amend legislative proposals and budgets; and a June 2020 virtual webinar with the European Environment Agency (EEA), whose role is to provide information on the environment for those involved in developing, adopting, implementing and evaluating environmental policy. These events, together with some related engagements and concurrent policy events are shown in Fig. 1. At all such events, we communicated in advance the aims, agenda, and how any feedback would be used, emphasising confidentiality, i.e. that nobody's contribution would be publicly-identifiable. Transdisciplinarity depends strongly on skills such as facilitation (Fam et al., 2016). As such, the planning and on-the-day running of all events was led by those of us with facilitation experience, collectively planning everything from invitations and venues through to event structure and facilitation prompts. We aimed to balance information-sharing and discussion, to encourage as many attendees as possible to contribute, and to introduce our own questions but also respond to attendee questions and ideas. We distributed feedback forms after events, to allow additional reflection and encourage individual perspectives that may not have been aired during collective discussion. The results section provides more information on our shifting engagement strategy.

3. Method

This paper is an auto-ethnographic reflection (White, 2011) of our personal experiences of evolving expert roles. This was an emergent issue noted by the authors during methodological planning, implementation, appraisal and reflections throughout the MAGIC project. As noted above, we focus here on our work on agricultural sustainability, together with the work that preceded and informed it: we do not claim to represent the full range of experiences and viewpoints of the wider MAGIC consortium, nor those of policy-makers with whom we engaged.

The main data sources used are (i) meeting notes (taken from within-organisation meetings, as well from consortium-wide meetings) (ii) memos and records of external interviews and meetings to engage with policy-makers (both during the events listed above and in any other interactions e.g. during conference attendance), and (iii) post-meeting feedback forms returned by participants after engagement events. We also draw on personal knowledge of our own and colleagues' backgrounds, and on interview data where policy-makers describe their backgrounds and expertise. We appraised these data to understand evolving scientific experts' preferences and behaviours, and in the correspondence with the expert roles or modalities outlined by Turnhout (2019).

This is a deductive analysis where we apply Turnhout's typology to help us understand and reflect on the emergent issue of our expert roles. Our results below do not arise from formal analysis using software, but subject to extensive team-based reflection, with our intentions for science-policy interactions discussed and challenged within internal consortium meetings, and finally discussed at the 2020 PNS5 Symposium[5] at the end of the project. The MAGIC research process received ethics approval from the James Hutton Institute Research Ethics Committee, and all data collected was processed in accordance with GDPR.

4. Results

4.1. Initial expectations of scientific expert roles

Scientific experts from different disciplines were required, by the project's design, to meet and collaborate with each other in interdisciplinary research, shaping each others' analyses: the original proposal and grant agreement made frequent references to 'mixed qualitative-quantitative tools' and partners in the consortium partially justified themselves on the basis of their experience in interdisciplinarity. Implementing QST was intended to promote iterative cycles of reflection and analysis that was not only interdisciplinary, but also transdisciplinary: that is, informed and influenced by the active participation of and co-analysis with policy-makers. There was no detailed prescription for how scientific experts should initiate or behave in these interactions, but there was a requirement for each QST cycle to have one or more meetings involving participation by policy-makers. In these interactions, scientists were expected to be open to understanding and responding to policy-maker visions and views, for example by adapting what aspects of agricultural systems were explored by the societal metabolism accounting, and with what data. This best fits with the ethos of the **broker role**, where scientists bring together different knowledges and values of relevance to policy, including their own. For example, when social scientists carried out early interviews with policy-makers, we often represented ourselves as intermediaries between policy and other colleagues, explaining we would *"feed"* or "*pass back*" interviewees' ideas or problems to the colleagues conducting quantitative analysis.

The expected work did not closely align with the **servicing role**. MAGIC planned to stimulate "*a better understanding*" of nexus interactions and policy interlinkages, so *"generating with stakeholders alternative formulations of nexus security"* (p.3 and p.23 in our 2016 Grant Agreement). To conform with the funder's evaluation criteria, which tend to favour demonstrable instrumental utility, this text did also describe its method as responding to the *"needs for advice of different DGs*" and providing *"'on the flight' advice to the EC about the timelines and soundness for the EU 2020 Strategy and the EU position in international agreements of EU policies…and targets"*. However, beyond this, the project text generally avoided promising that it would 'solve' the immediate

[5] The Post-Normal Science 5 Symposium, 21–25/09/2021 https://pns5.biostatistica.net/

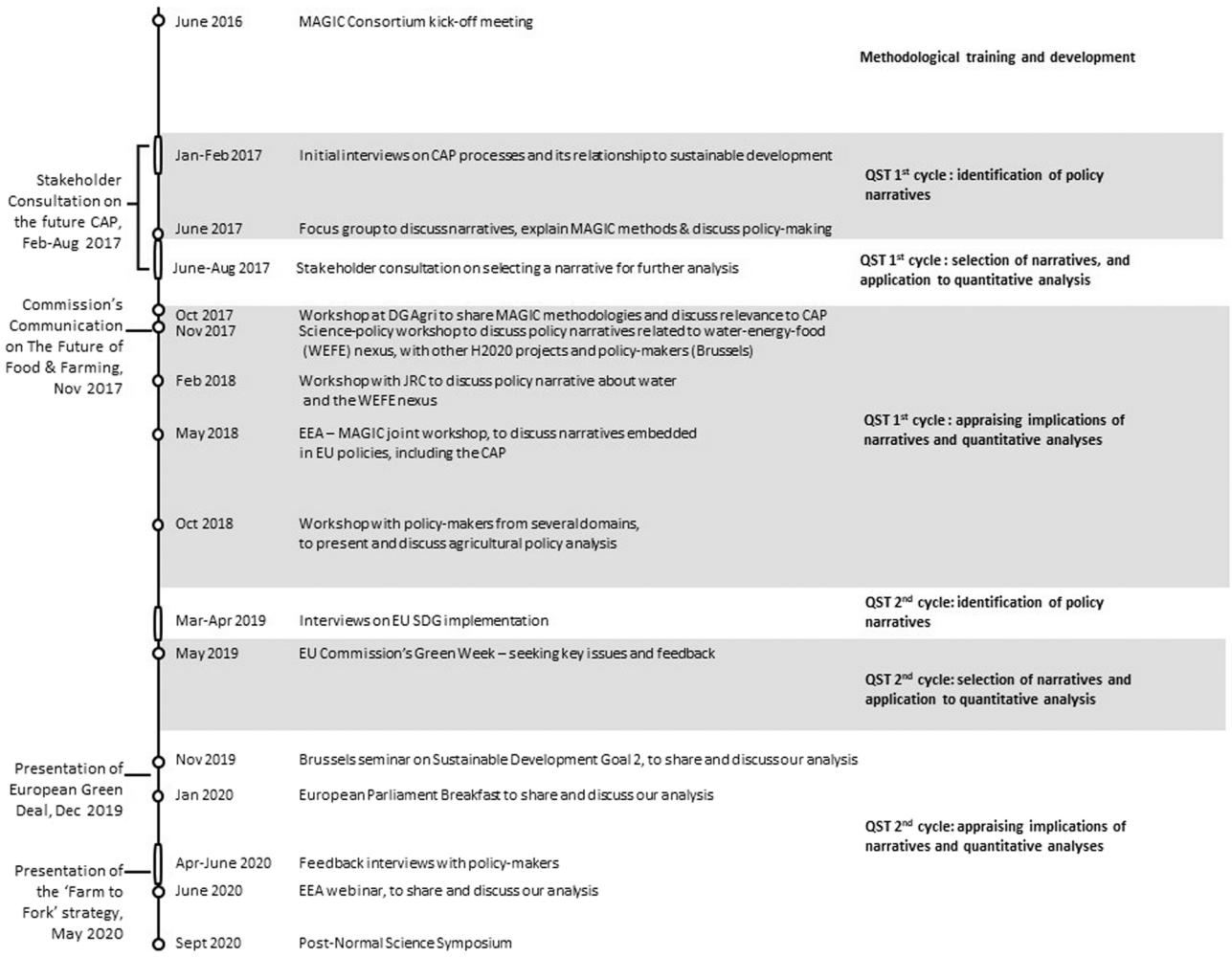

Fig. 1. A visual overview of key steps in our MAGIC research focused on agriculture. Consult supplementary material for more information about specific steps.

needs of policy-makers.

Once the project secured funding, there was less need to claim instrumental utility by providing immediate answers and insights for pre-existing policy questions and processes. Instead, in early internal meetings many senior project members emphasised that policy-makers needed to question their problem framings and contemplate radical changes, stating that current policies were often inadequate to the scale and scope of sustainability challenges. This normative position might be expected to automatically translate into an **advocacy role** for the scientists – critiquing existing problem framings. However, during the first year of the project, such views were not expressed in early interactions with policy-makers, as the social scientists responsible for initiating policy engagement largely focused on understanding policy processes and stakeholders, and explaining what they knew of the MAGIC methodologies, including both some overview of the technicalities of QST and the ethos of aiming to engage with policy-makers in discussing implications. Meanwhile, other colleagues expected that presentation of data related to sustainability, even without making their own views explicit, would "speak for itself" and so inexorably lead policy-makers to agree on the need for radical policy and societal change.

4.2. Evolving roles of scientific experts

Throughout 2017 we accrued experience of identifying and interacting with policy-makers in interviews, emails and face-to-face interactions. Partially influenced by these interactions, our societal metabolism analysis focused on the sustainability of agricultural systems. These interactions did partially reflect our intention for an iterative and interactive process, but it did not proceed entirely as envisaged in the project plan. Firstly, identifying and contacting policy-makers took even more effort than we had initially imagined. Then, after establishing contact we often then struggled to build relationships. This was not helped by our keenness to critically discuss sustainability and query policy. It appeared many policy-makers did not feel comfortable sharing any opinions in a professional capacity, though this depended on personality and position. This was especially true for any opinions that could be seen to criticise current policy: even though all the discussions and feedback were clearly explained to be confidential, with no contributor ever being publicly identifiable. For example, in response to routine requests for post-event feedback, one participant declined giving ratings on progress to sustainability, describing it as "*intrusive, in terms of passing judgement over policy*". Our aspirations to build in-depth relations were also challenged by different sets of people engaging with different events and engagements. Whilst this 'churn' was not entirely unexpected, this resulted in the social scientists who led the engagement further adapting their approach to promote the salience of MAGIC. In some meeting invitations, we emphasised the role of MAGIC in presenting "*an overview*" of data and issues related to agricultural sustainability, giving less emphasis to potential discussion and debate over policy itself. For example, our invitation to our October 2018 meeting, to discuss our first stage of analysis, said there would be discussion following presentations: "*we would very much value your thoughts on this analysis – whether you find it interesting, helpful – and also your own perspective and ideas on useful next steps*". This framing emphasised

seeking feedback to enable our work to have instrumental value to them, rather than to explore the suitability or framing of policy issues. During these meetings some scientists also emphasised their knowledge of policy processes and practicalities, to build rapport and build confidence with new contacts. Thus, the **broker role** was, to some extent, maintained.

The broad structure of meetings with policy-makers was to share the overall methodology, present data analysed by the MAGIC team, then briefly give our interpretations and conclusions, before asking the policy-makers for their own reactions and interpretations. Our analyses suggested many agricultural processes are associated with high flows of resources (e.g., water extraction, pollution loading), that place pressures on natural systems, so our own conclusions were that significant changes were needed that could not be achieved by minor adjustments to existing policy measures, but that might imply radical change in or removal of high-level policy, especially CAP. As such, these final conclusions were explicitly normative, by critiquing aspects of the current situation. This may have been slightly unexpected for some policy-makers. It is not that we had intended to mislead them, in the framing of our invitations; but we aimed to present both empirical results *and* also draw out implication and highlight alternative narratives. The latter content was not always expected or welcome in a context where policy institutions are used to commissioning science to serve rather than critique policy processes.

The explicit normative position is also reflected in the content and labelling tangible outputs such as 'concern sheets' instead of more neutral 'research briefings'. To some extent this **advocacy role** strengthened over the course of the project: by the time of the final in-person interaction with the European Parliament in January 2020, the limited presentation time was used to focus on a few slides highlighting a few high pressures associated with certain agricultural processes, closely linked to statements about the unsustainability of current agricultural policies. This generated concerned responses e.g. that the situation was "*scary*" and some debate about the scope and pace of policy changes needed. It was interesting that this debate arose with Parliamentarians and their officials, much more so than in interactions with staff from the Commission.

Our project team's normative views and critiques of the current policy process were more clearly articulated in our later-stage interactions: both in the conclusion to presentations and in some of our responses during discussions. Yet we also noticed that during later-stage interactions, a few of us – those with responsibility for recruiting and maintaining policy engagement – reacted to policy-maker criticisms or lack of enthusiasm for our work, by asking how our future work could "*complement what you are already doing*" and what changes would be needed for our work to be "*really useful*". These responses would lead us to conform with existing framings of the science-policy interface, and to support decision-making in a manner that would more closely conform with the **servicing** role. One of us noticed that we had initially crafted invitations and initiated discussions with relatively neutral language, akin to a broker role; but when faced in person with doubts and questions from policy-makers we shifted to exploring their current needs, whilst adopting body language and facial expressions that were indicative of being 'eager to please'. In summary, different scientific experts in our team were adopting different roles, and even slightly shifting in roles during the course of one interaction. We explore more about why this occurred in the following sections.

4.3. Why and how these roles were adopted

Our evolving roles arose in response to the varied reactions of policy-makers and our personal reactions to them and each other.

Where we presented our analyses to staff from the European Commission as in October 2018 and November 2019 events – their individual reactions varied, but rarely touched on the need to change current policy processes. Instead, the bulk of questions and comments related to querying the datasets used in societal metabolism analysis, contesting details of language or presentation. For example, after we presented our interpretation of the data – that we believed change in CAP was needed for agriculture to become sustainable, one policy-maker responded by asking that we instead describe it as merely needing to become '*more sustainable*'. The same person also asked us to describe the limitations of the dataset we used, which was the Commission's own data and the formal basis of policy implementation appraisal. We had expected that stakeholders would wish to probe and check the material presented, yet even so we were surprised by how negative this felt and how difficult it was to move beyond questions or comments on details. In our internal debriefing discussions after our 2018 and 2019 policy workshops, we speculated that focusing on data, definitional and methodological queries might be a form of deflection, to avoid discussing any bigger implications that would follow from accepting that agricultural systems and agricultural policy required significant change. We did feel that our willingness to respond to queries in the 2018 meeting, as well as our adapted presentations, lessened this critique during the 2019 event, but it was still a significant theme. Interestingly, an interaction with the EEA in summer 2020 – based around similar content – played out quite differently. Although it might be expected that the EEA analysts would be more focused on exploring details of the data and methodology, our discussion actually spent much less time probing or contesting details, and was more focused on what the implications were for policy and policy support.

In the October 2018 and November 2019 events, a couple of participants asked for more tailored and specific policy recommendations that they could feed into their ongoing work. We felt this conflicted with other feedback which, as noted above, we felt pushed us to avoid discussion of policy implications. However, such requests for policy recommendations would fit well with expectations of scientists playing a servicing role, if we were asked to focus our input into supporting the detail of how to implement ongoing policy processes, rather than critiquing them. Such requests may reflect the mandates and professional tasks of the attendees, as well as their previous experiences of interacting with researchers commissioned to inform and refine specific policy processes, rather than question the broad structure of the policies themselves.

The reactions of the scientists in the presenting team also diverged. Our lead expert in the societal metabolism analysis focused on explaining and defending the details of its application, and reiterating the team's interpretations and conclusions. They also mentioned experience of policy-maker relationships and relevance in other contexts, to bolster their credibility. In the same meetings, another scientist representing social science similarly attempted to signal their understanding of policy-maker processes and constraints, but also adopted an increasingly placatory tone, asking questions to elicit and understand policy-makers perceptions of what would be useful. This latter approach was motivated by wanting to maintain and build a fragile professional relationship they had initiated. This reaction was also a slightly instinctive avoidance of inter-personal conflict, and seeking to complement and soften the more defensive position of the colleague arguing for the value of our analyses. However, when there was more willingness to discuss the scale and scope of policy reform, during the January 2020 event at the Parliament, both experts behaved more similarly, in sharing more details of their analysis and speculating jointly with the policy-makers about useful interventions and future trajectories of change.

Thus, our differing approaches to policy-maker responses was influenced by our academic expertises and professional responsibilities, as well as the varied responses and professional roles of stakeholders themselves. To some extent these roles were foreseen, especially in later engagements, where we explicitly discussed beforehand the extent to which we would or would not present our own views on the implications of our analyses. However, the reactions were also very personal and instinctual during the moments of engagements, reflecting our personalities and relationships with each other.

The interpersonal politics of team work also shaped project work in-between instances of stakeholder engagement. This is especially true for team members based in one organisation, as there were numerous interactions during travel, and planned and unplanned interactions in the workplace. Interactions with the wider project consortium occurred at least annually in face-to-face meetings and in online and email interactions. Interpretation of experiences was often discursive, mutually shaping our views and expectations, though not rigidly constraining the tactics used in later encounters.

The lead investigator of MAGIC and other senior members of the consortium knew each other and had prior experience in societal metabolism method and its insights, though were not always experienced in policy processes and interactions. These prior experiences provided confidence in the validity of methods and the conclusions that could be drawn, tending to reinforce the advocacy position. Depending on the professional culture and hierarchies within organisations, the views of these senior staff influenced the plans and roles adopted by more junior staff and colleagues. Potentially this could have fostered groupthink and more consistent expert roles, but as we have shown during interactions with policy-makers, different MAGIC experts sometimes behaved differently. Significantly, all those directly involved in interactions had significant experience of research and policy-interactions, even if they were not lead investigators, so had confidence in forming their own responses during interactions. Additionally, for the team at the James Hutton Institute, senior staff explicitly encouraged input and ideas from all team members across departments: further fostering self-confidence in ideas, and a trust that differences would not be penalised.

4.4. Our reflections on positive and negative implications of these roles

Firstly we reflect on the **servicing role** . When interpersonal interactions with policy-makers felt challenging, the easiest response for some of us was to respond by asking about their immediate policy needs. Lapsing into this role could seem the path of least resistance because it reflects familiar science-policy relationships explicitly and implicitly expected by many. Additionally, the information or insights produced by this way of working can neatly align within and support existing policy processes, rather than raising new inconvenient questions, or jeopardising the policy itself. A positive implication of this role is that it may build a relationship of trust, after which perhaps experts could consider interacting in other ways. However, it is unclear how long this would take – it was not possible to judge from the few interactions within MAGIC. On the negative side, until new roles can be adopted, the full range of insights from scientists (and policy-makers) may not be shared or used, and the distinction between science and policy is reinforced.

Secondly, acting in the **broker role** also sometimes felt attractive or convenient. The positive implication of doing so was the potential to build trust, as much as or even more than in the servicing role, if the broker appears to be neutrally compiling multiple sources of knowledge and viewpoints. However, a negative implication is that individual scientists acting on this may focus on their facilitation role and expertise at the expense of their own academic expertise. For example, during interactions with policy-makers, one of the social scientists in our team realised that in their interactions they often attempted to emphasise their knowledge of the practical realities of European policy processes, whilst also downplaying their academic expertise and insights for sustainability arising from policy analysis. Afterwards, they felt they had inadvertently been disingenuous, in never mentioning this and their own convictions about the implications.

Lastly, acting in the **advocacy role** may be positive if the passion and conviction of the scientist intrigues and inspires the interest of the policy-makers, and is laudable for making a scientist's values and viewpoint transparent and explicit. However, if policy-makers feel this to be inappropriate, and are unwilling or unable to fully engage with debate on problem framings, this can have negative implications. For example, when one MAGIC expert presented strong normative views in a meeting with policy-makers – stating bluntly that certain aspects of policy were unsustainable and should be changed – we observed several policy-makers with body language shifted to suggest disquiet or unease, and who then asked questions that felt like attacks or made disapproving comments. Whilst uncomfortable interactions can be productive, provoking defensiveness may close down debate and not foster an extended peer community.

5. Discussion

Within the MAGIC project, scientific experts from multiple disciplines attempted to build new relationships with EU policy-makers and other officials connected to the nexus of agricultural-sustainability issues, to generate discussion and reflection on sustainability. This process was, to some extent, productive and successful: new interactions occurred, new analyses were shared, sometimes generating wide-ranging discussion on sustainability and European policy. However, our interactions with policy-makers did not simply or easily conform with our aspirations for post-normal science. As per the typology of Turnhout (2019) our aspirations for ourselves were mostly associated with brokerage and some advocacy, but in practice we tended more to servicing and advocacy roles.

Table 1 summarises our view about the individual and contextual factors that shaped our experiences and behaviours as experts interacting with policy-makers, explaining the roles we adopted. Often individuals moved between roles over time or in different settings, reacting to policy-makers, each other and different contexts, some becoming more entrenched in their expectations and styles of interaction. Our experiences confirm that Turnhout's typology is a very useful heuristic for thinking about how individual roles explain and interplay with project achievements, and emphasise that it must not be used in a rigid or static way. The roles of scientific experts must be seen as a dynamically constructed – and indeed one potentially co-constituted not only with each other, but also with policy-makers.

Some of these factors interacted to make our experiences uncomfortable, largely because an ethos of post-normal science does not easily align with the institutionally available repertoires and modes of interaction typically encouraged or available to policy-makers. Post-normal science encourages us to discuss uncertainty, values and stakes, challenging the established 'linear model' of knowledge production and use. Our attention to expert roles was an emergent issue throughout our research: earlier and more explicit reflection on our roles and interactions might have helped us to articulate and navigate the discomfort, but not remove it. Thus, we do not think our experiences are unique

Table 1
Potential factors shaping scientific expert roles during interactions with policy-makers, based on observation and inference during our research.

Scientific expert	*Personality*
	Confidence in scientific methods and conclusions
	Disciplinary background
	Experience of policy interactions and/or processes
	Other experience & expertise (especially in facilitation)
Research design and content	*Plans for stakeholder mapping & engagement*
	Capacity to invest in stakeholder recruitment & conversations
	Extent to which research approach and outputs are uncomfortable/ fit with pre-existing knowledge used in policy institutions
Research team	*Professional hierarchies /institutional ordering within scientific organisations*
	Interactions across organisations in consortia
Policy-maker	*Personality*
	Familiarity with scientific processes and projects
	Professional requirements and responsibilities of role
	Timing in policy processes

to MAGIC, but discomfort would likely be experienced by other teams or in other projects reflecting the post-normal ethos.

Post-normal science takes both scientists and policy-makers out of their established roles of "fact providers" and "fact receivers". Indeed, such processes may be just as uncomfortable for policy-makers as for researchers. Large complex institutions – like the European Commission and other policy-making settings – do not usually accommodate radical transformation (Rayner, 2012). During our engagements the Commission was referred to as an 'oil tanker' that does not easily change course; the comment was meant positively, for ensuring stability, but of course this also impedes change. Additionally, our analyses and implications could imply some significant critique of policies such as CAP, and so could feel personally destabilising for those individuals where refining implementation of this policy is their professional focus. Politicians – as we found when engaging with parliamentarians – may potentially be more open to discussing policy problems and alternative problem framings. Thus more attention is needed to the concrete sites of engagement, underlying political philosophies and individual stances (Laurent, 2017).

PNS already encourages us to involve an extended peer community including science, policy and other stakeholders. This could be interpreted as abandoning the concept of individual experts and expertise. However, we suggest that delineating the multiple expertises and roles of all individuals may help to promote reflexivity and put PNS into practice. This can be achieved by revisiting discussions on expertise, its recognition, types, development (e.g. Rip, 2003). If all knowledge and values are valid, then thinking through everyone's expertise and expected roles can consolidate appreciation of this and practically plan PNS. For example, anyone intending to promote PNS can ask: *"How and why have we presented ourselves as experts, what does this mean for our future work and desire to initiate conversations and change?"* All individuals involved – both experts from academia and in other settings – can then benefit from explicitly reflecting on this throughout their work. Attention to these issues by those inside and outside of academia is essential. We next consider additional perspectives that may enrich and extend this work.

5.1. Implications for practicing and developing PNS

The scale of nexus challenges generate the need for post-normal science (Ravetz, 2018), yet achieving sustainability entails wide-ranging transformation that may conflict with existing rationalities and interests (Stirling, 2008). Thus, initiating processes of post-normal science may be most challenging in exactly those situations where it is most required.

Carefully considering tools and approaches that may promote transformative reframing may help with this challenge: for example, Hoolohan et al. (2018) demonstrates how nexus perspectives can be promoted by methods to visualise systems, in tandem with approaches to widen participation and inclusion of knowledges; whilst Saltelli et al. (2020) has compared the value analytical tools as 'lenses' that promote reflexivity on sustainability challenges. However, it is important that uncomfortable experiences are not seen as something that can – or even should – be fixed by specific tools or techniques.

Insights from literatures on science-policy interfaces (e.g. Hoppe, 2005) and social learning (e.g. Colloff et al., 2017; Pahl-Wostl et al., 2013) provide insight into some aspects of these challenges, and ideas for building relationships across epistemological and institutional boundaries. A common message is that more time helps to build relationships between scientific experts and policy-makers that foster trust and deepen mutual understanding (Young et al., 2014), so allowing discussions to become more wide-ranging or provocative. This relates to the idea of moving from single- to double- or triple-loop learning in the social learning literature, i.e. from refining how problems are solved to reconsidering the problems themselves. However, we cannot assume that the luxury of more time will always and automatically result in more wide-ranging reflection and reframing; achieving this requires careful and sustained attention (Medema et al., 2014).

To ensure reflection and promote reframing, explicit planning for this is needed from the earliest stages of a process. This should consider when and how to consider mix different perspectives to foster reframing, work with conflicts, address power and foster creativity (Colloff et al., 2017). Power dynamics within a team, including the confidence and openness of senior staff, are likely to be strong influences, but are often not well acknowledged (Hall et al., 2018). Our team did not explicitly discuss how seniority, experience, discipline and even gender would affect our work process, but it would be productive for others to do so. Later, there should be regular review of experiences and progress in reframing. This could result in refinement of specific activities but also potentially redesign of the process, and reframing by the academic experts themselves. Many teams already reflect informally, through chats and debriefings, and this could be strengthened by formalising the process of reflection, informed by relevant literatures. This includes literatures mentioned above on science-policy interfaces (Young et al., 2014) and social learning (e.g. Colloff et al., 2017; Medema et al., 2014), as well as other learning traditions (e.g. van Mierlo and Beers, 2020). However, retaining the focus on individuals is necessary. To achieve this, the reflections on expert roles from Turnhout (2019) are very useful, including consideration of what Turnhout calls the institutional context or what others refer to as the imaginative resources available to make sense of a given situation (Smallman, 2020). Future work may also benefit from incorporating perspectives from team-based sciences (e.g. Hall et al., 2018), power (Svarstad et al., 2018) and stakeholder roles (Schmidt et al., 2020) as well as any empirical experiences of individuals attempting to build new relationships and ways of working outside of academia (e.g. Wye et al., 2019).

It will be valuable to synthesise insights all these varied literatures – i.e. on science-policy interfaces, social learning, boundary-spanning – balancing attention individual, team and institutional dynamics. This can potentially focus around testing the validity of Table 1. We also suggest that interrogating interactions and tensions may be a useful focus for future work. These interactions include: between individuals adopting different expert roles; between different forms of scientific and non-scientific expertise; and between the different roles adopted by one individual over time.

5.2. Strengthening the policy perspective

This paper has been written solely from the perspective of scientific experts, but policy-makers will have their own perspectives, reflecting their expectations and own expertises. We note the boundaries between scientist and policy-maker can blur, especially when staff are employed in specialist analyst roles within policy institutions, or within agencies such as the European Environment Agency. For example, some of the Commission staff that we engaged with had prior careers in which they were at the cutting edge of developing techniques ranging from econometric analyses or climate models. This said, the particular responsibilities and roles of those in policy-making institutions make the distinction useful (Posner and Cvitanovic, 2019).

Future learning would greatly benefit from reports of policy-maker experiences and expectations – whether of interacting with this or other scientific projects. This would allow better understanding of the institutional context which conditions and constrains their interactions and activities. However, a pervasive problem when theorising and attempting to improve science-policy relationships is a lack of policy-led empirical accounts of policy processes, actors and institutions. Academic scientists can and should do more (Clark et al., 2016), but change cannot be achieved solely by scientists (Wittmayer et al., 2020).

The need for more access into policy is a fundamental challenge which relates to policy institutions' appetite and ability to countenance change. Achieving sustainability transitions is widely recognised to depend on reform of policy systems as well as knowledge systems

(Oliver et al., 2021). Specifically, governance systems and actors need to not only to voice support for concepts such as the nexus; but also go beyond this to embed reflexivity, widen perspectives employed, and 'open up' to new knowledges and new science-policy relationships (Urbinatti et al., 2020).

Full appreciation of the complexity of sustainability challenges ultimately entails accepting uncertainty and limits to control, lowering expectations about how likely any problem can be 'solved' by new knowledges – which is not easy (Strand, 2002). As a result, approaches such as PNS, that promote reframing and raise these issues will tend to be resisted. However, policy-makers and institutions vary in their views. For those within or outside policy institutions who are contemplating the need for change, it will be useful to consult some of the same literatures recommended for supporting reflection and guide action by researchers. These include how to frame and promote individual and institutional learning and reflection, including social learning (Pahl-Wostl et al., 2013), also on deliberative policy evaluation (Fischer, 2007). The individual perspective can be balanced by insights on navigating systemic change; including institutional and organisational studies (Beunen and Patterson, 2019), transitions (Patterson, 2021), transformations (Muiderman et al., 2022) and levers and leverage points (Dorninger et al., 2020). In short, identifying how to re-organise governance systems and science-policy relations for sustainability transformations is a vital challenge that requires attention to both individuals and institutions within both academia and policy settings.

6. Conclusion

This study reports experiences of trying to implement post-normal science within part of the 'MAGIC' project. We demonstrate that it is not easy to initiate new science-policy relationships that may potentially entail reframing policy for sustainability. Attempting to discuss 'uncomfortable knowledge' (Rayner, 2012) can result in an uncomfortable process. This has not been widely acknowledged. We thus contribute and call for more discourse reflecting on the role of science and scientists in transdisciplinary settings. In particular, we highlight a need for more attention to the potentially plural roles of experts. Turnhout's (2019) typology of experts is a useful starting point for understanding how individuals act and interact to shape the scientific processes, but more work is needed to understand the contingent nature of practices that co-produce knowledge, shape its use and indeed shape experts within and beyond academia. Future attention to individuals in both science and policy settings will strengthen post-normal science, and indeed all transdisciplinary science for sustainability.

Declaration of Competing Interest

All the authors report financial support was provided by European Union Horizon 2020 which may have affected our views and relationships with European Commission staff and processes.

Data availability

The data that has been used is confidential.

Acknowledgements

The MAGIC project was funded by the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No. 689669, and James Hutton Institute researchers were also supported by the Rural & Environment Science & Analytical Services Division of the Scottish Government, as part of the 2016–2022 Strategic Research Programme. MG acknowledges financial support by the Spanish Ministry of Science and Innovation (MICINN) through the "María de Maeztu" program for Units of Excellence (CEX2019-000940-M). This work reflects the authors' view only; the funding agencyies are not responsible for any use that may be made of the information it contains. We are grateful to all policy experts and other stakeholders who interacted with us, to Lorenzo Benini and Gary Polhill for feedback during manuscript development, and two anonymous reviewers.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2023.01.007.

References

Beck, S., Borie, M., Chilvers, J., Esguerra, A., Heubach, K., Hulme, M., Lidskog, R., Lövbrand, E., Marquard, E., Miller, C., Nadim, T., Neßhöver, C., Settele, J., Turnhout, E., Vasileiadou, E., Görg, C., 2014. Towards a reflexive turn in the governance of global environmental expertise. The cases of the IPCC and the IPBES. GAIA Ecol. Perspect. Sci. Soc. 23 (2), 80–87. https://doi.org/10.14512/gaia.23.2.4.

Beunen, R., Patterson, J.J., 2019. Analysing institutional change in environmental governance: exploring the concept of 'institutional work'. J. Environ. Plan. Manag. 62 (1), 12–29. https://doi.org/10.1080/09640568.2016.1257423.

Buschke, F.T., Botts, E.A., Sinclair, S.P., 2019. Post-normal conservation science fills the space between research, policy, and implementation. Conserv. Sci. Pract. 1 (8), e73 https://doi.org/10.1111/csp2.73.

Cairns, R., Krzywoszynska, A., 2016. Anatomy of a buzzword: the emergence of 'the water-energy-food nexus' in UK natural resource debates. Environ. Sci. Policy 64, 164–170. https://doi.org/10.1016/j.envsci.2016.07.007.

Chilvers, J., 2013. Reflexive engagement? Actors, learning, and reflexivity in public dialogue on science and technology. Sci. Commun. 35 (3), 283–310. https://doi.org/10.1177/1075547012454598.

Clark, W.C., Van Kerkhoff, L., Lebel, L., Gallopin, G.C., 2016. Crafting usable knowledge for sustainable development. Proc. Natl. Acad. Sci. USA 113 (17), 4570–4578. https://doi.org/10.1073/pnas.1601266113.

Collins, H.M., Evans, R., 2002. The third wave of science studies: studies of expertise and experience. Soc. Stud. Sci. 32 (2), 235–296. https://doi.org/10.1177/0306312702032002003.

Colloff, M.J., Lavorel, S., van Kerkhoff, L.E., Wyborn, C.A., Fazey, I., Gorddard, R., Mace, G.M., Foden, W.B., Dunlop, M., Prentice, I.C., Crowley, J., Leadley, P., Degeorges, P., 2017. Transforming conservation science and practice for a postnormal world. Conserv. Biol. 35 (1), 1008–1017. https://doi.org/10.1111/cobi.12912.

Décieux, J.P.P., 2020. How much evidence is in evidence-based policymaking: a case study of an expert group of the European Commission. Evid. Policy J. Res. Debate Pract. 16 (1), 45–63. https://doi.org/10.1332/174426418×15337551315717.

Dolter, B., 2021. Greening the Saskatchewan grid: a case study in deliberative energy modelling. Ecol. Econ. 183, 106966 https://doi.org/10.1016/j.ecolecon.2021.106966.

Dorninger, C., Abson, D.J., Apetrei, C.I., Derwort, P., Ives, C.D., Klaniecki, K., Lam, D.P. M., Langsenlehner, M., Riechers, M., Spittler, N., von Wehrden, H., 2020. Leverage points for sustainability transformation: a review on interventions in food and energy systems. Ecol. Econ. 171, 106570 https://doi.org/10.1016/j.ecolecon.2019.106570.

European Commission, 2001. European Governance: A White Paper. Office for Official Publications of the European Communities, Brussels.

Blackstock, K.L., Waylen, K.A., Matthews, K.B., Juarez-Bourke, A., Miller, D., Hague, A., Wardell-Johnson, D., Giampietro, M., 2023. Implementing post-normal science with or for EU policy actors: Using Quantitative Story Telling. Sustain. Sci. https://doi.org/10.1007/s11625-022-01265-1.

Fam, D., Smith, T., Cordell, D., 2016. Being a transdisciplinary researcher: skills and dispositions fostering competence in transdisciplinary research and practice. In: Fam, D., Palmer, J., Riedy, C., Mitchell, C. (Eds.), Transdisciplinary Research and Practice for Sustainability Outcomes. Routledge, London, UK, pp. 77–92.

Fischer, F., 2007. Deliberative policy analysis as practical reason: integrating empirical and normative arguments. In: Fischer, F., Miller, G.J. (Eds.), Handbook of Public Policy Analysis. Routledge, New York, p. 14.

Funtowicz, S.O., Ravetz, J.R., 1991. A new scientific methodology for global environmental issues. Ecological Economics: The Science and Management of Sustainability. Columbia University Press, New York, pp. 137–152.

Funtowicz, S.O., Ravetz, J.R., 1993. Science for the post-normal age. Futures 25 (7), 739–755. https://doi.org/10.1016/0016-3287(93)90022-L.

Game, E.T., Meijaard, E., Sheil, D., McDonald-Madden, E., 2014. Conservation in a wicked complex world; challenges and solutions. Conserv. Lett. 7 (3), 271–277. https://doi.org/10.1111/conl.12050.

Giampietro, M., Mayumi, K., 2000. Multiple-scale integrated assessment of societal metabolism: introducing the approach. Popul. Environ. 22 (2), 109–153. https://doi.org/10.1023/A:1026691623300.

Gluckman, P., 2014. Policy: the art of science advice to government. Nature 507 (7491), 163–165. https://doi.org/10.1038/507163a.

Hall, K.L., Vogel, A.L., Huang, G.C., Serrano, K.J., Rice, E.L., Tsakraklides, S.P., Fiore, S. M., 2018. The science of team science: a review of the empirical evidence and research gaps on collaboration in science. Am. Psychol. 73 (4), 532–548. https://doi.org/10.1037/amp0000319.

Hart, H., Bas-Defossez, F., 2018. CAP 2012–27: proposals for increasing its environmental and climate ambition, report for NABU by IEEP, Istitute for European Environmental Policy (IEEP). ⟨http://capreform.eu/how-to-improve-the-caps-environmental-performance-post-2020/⟩.

Hodson, D., Puetter, U., Peterson, J., Saurugger, S., 2022. The Institutions of the European Union. Oxford University Press, Oxford, UK.

Hoolohan, C., Larkin, A., McLachlan, C., Falconer, R., Soutar, I., Suckling, J., Varga, L., Haltas, I., Druckman, A., Lumbroso, D., Scott, M., Gilmour, D., Ledbetter, R., McGrane, S., Mitchell, C., Yu, D., 2018. Engaging stakeholders in research to address water–energy–food (WEF) nexus challenges. Sustain. Sci. 13 (5), 1415–1426. https://doi.org/10.1007/s11625-018-0552-7.

Hoppe, R., 2005. Rethinking the science-policy nexus: from knowledge utilization and science technology studies to types of boundary arrangements. Poiesis Prax. Int. J. Technol. Assess. Ethics Sci. 3 (3), 199–215. https://doi.org/10.1007/s10202-005-0074-0.

Jasanoff, S., 2003. Breaking the waves in science studies: comment on H.M. Collins and Robert Evans, `The Third Wave of Science Studies'. Soc. Stud. Sci. 33 (3), 389–400. https://doi.org/10.1177/03063127030333004.

Jasanoff, S. (Ed.), 2004. States of Knowledge. The Co-Production of Science and Social Order. Routledge, London and New York.

König, A., 2018. Systems approaches for transforming social practice: design requirements. In: König, A., Ravetz, J.R. (Eds.), Sustainability Science: Key Issues. Routledge, London, pp. 55–81.

Laurent, B., 2017. Democratic Experiments: Problematizing Nanotechnology and Democracy in Europe and the United States. The MIT Press.

Mason, N.W.H., Burge, O., Price, R., Sprague, R., Dymond, J., Watt, M., Roberts, T., Paul, T., Richardson, B., Rolando, C., Wyse, S., Hulme, P.E., Stahlmann-Brown, P., Awatere, S., Peltzer, D.A., 2021. Integrating across knowledge systems to drive action on chronic biological invasions. Biol. Invasions 23 (2), 407–432. https://doi.org/10.1007/s10530-020-02388-1.

Matthews, K.B., Rivington, M., Blackstock, K., McCrum, G., Buchan, K., Miller, D.G., 2011. Raising the bar? – The challenges of evaluating the outcomes of environmental modelling and software. Environ. Model. Softw. 26 (3), 247–257. https://doi.org/10.1016/j.envsoft.2010.03.031.

Matthews, K.B., Renner, A., Blackstock, K.L., Waylen, K.A., Miller, D.G., Wardell-Johnson, D.H., Juarez-Bourke, A., Cadillo-Benalcazar, J., Schyns, J.F., Giampietro, M., 2021. Old wine in new bottles: exploiting data from the EU's farm accountancy data network for Pan-EU sustainability assessments of agricultural production systems. Sustainability 13 (18), 10080. https://doi.org/10.3390/su131810080.

Medema, W., Wals, A., Adamowski, J., 2014. Multi-loop social learning for sustainable land and water governance: towards a research agenda on the potential of virtual learning platforms. NJAS Wagening. J. Life Sci. 69, 23–38. https://doi.org/10.1016/j.njas.2014.03.003.

van Mierlo, B., Beers, P.J., 2020. Understanding and governing learning in sustainability transitions: a review. Environ. Innov. Soc. Transit. 34, 255–269. https://doi.org/10.1016/j.eist.2018.08.002.

Muiderman, K., Zurek, M., Vervoort, J., Gupta, A., Hasnain, S., Driessen, P., 2022. The anticipatory governance of sustainability transformations: hybrid approaches and dominant perspectives. Glob. Environ. Change 73, 102452. https://doi.org/10.1016/j.gloenvcha.2021.102452.

Nutley, S., Morton, S., Jung, T., Boaz, A., 2010. Evidence and policy in six European countries: diverse approaches and common challenges. Evid. Policy J. Res. Debate Pract. 6 (2), 131–144. https://doi.org/10.1332/174426410×502275.

Oliver, T.H., Benini, L., Borja, A., Dupont, C., Doherty, B., Grodzińska-Jurczak, M., Iglesias, A., Jordan, A., Kass, G., Lung, T., Maguire, C., McGonigle, D., Mickwitz, P., Spangenberg, J.H., Tarrason, L., 2021. Knowledge architecture for the wise governance of sustainability transitions. Environ. Sci. Policy 126, 152–163. https://doi.org/10.1016/j.envsci.2021.09.025.

Pahl-Wostl, C., Becker, G., Knieper, C., Sendzimir, J., 2013. How multilevel societal learning processes facilitate transformative change: a comparative case study analysis on flood management. Ecol. Soc. 18 (4) https://doi.org/10.5751/ES-05779-180458.

Patterson, J.J., 2021. Remaking political institutions in sustainability transitions. Environ. Innov. Soc. Transit. 41, 64–66. https://doi.org/10.1016/j.eist.2021.10.011.

Pereira, L., Karpouzoglou, T., Doshi, S., Frantzeskaki, N., 2015. Organising a safe space for navigating social-ecological transformations to sustainability. Int. J. Environ. Res. Public Health 12 (6), 6027–6044. https://doi.org/10.3390/ijerph120606027.

Pielke, J.R.A., 2007. Four idealized roles of science in policy and politics. In: Pielke, J.R.A. (Ed.), The Honest Broker: Making Sense of Science in Policy and Politics. Cambridge University Press, Cambridge, pp. 1–7.

Popa, F., Guillermin, M., Dedeurwaerdere, T., 2015. A pragmatist approach to transdisciplinarity in sustainability research: from complex systems theory to reflexive science. Futures 65, 45–56. https://doi.org/10.1016/j.futures.2014.02.002.

Posner, S.M., Cvitanovic, C., 2019. Evaluating the impacts of boundary-spanning activities at the interface of environmental science and policy: a review of progress and future research needs. Environ. Sci. Policy 92, 141–151. https://doi.org/10.1016/j.envsci.2018.11.006.

Ravetz, J., 2004. The post-normal science of precaution. Futures 36 (3), 347–357. https://doi.org/10.1016/S0016-3287(03)00160-5.

Ravetz, J.R., 2018. Post-script: heuristics for sustainability science. In: K. A, Ravetz, J.R. (Eds.), Sustainability Science: Key Issues. Routledge, London, pp. 337–344.

Rayner, S., 2012. Uncomfortable knowledge: the social construction of ignorance in science and environmental policy discourses. Econ. Soc. 41 (1), 107–125. https://doi.org/10.1080/03085147.2011.637335.

Rip, A., 2003. Constructing expertise: in a third wave of science studies. Soc. Stud. Sci. 33 (3), 419–434. https://doi.org/10.1177/03063127030333006.

Saltelli, A., Giampietro, M., 2017. What is wrong with evidence based policy, and how can it be improved? Futures 91, 62–71. https://doi.org/10.1016/j.futures.2016.11.012.

Saltelli, A., Benini, L., Funtowicz, S., Giampietro, M., Kaiser, M., Reinert, E., van der Sluijs, J.P., 2020. The technique is never neutral. How methodological choices condition the generation of narratives for sustainability. Environ. Sci. Policy 106, 87–98. https://doi.org/10.1016/j.envsci.2020.01.008.

Schmidt, L., Falk, T., Siegmund-Schultze, M., Spangenberg, J.H., 2020. The objectives of stakeholder involvement in transdisciplinary research. A conceptual framework for a reflective and reflexive practise. Ecol. Econ. 176, 106751 https://doi.org/10.1016/j.ecolecon.2020.106751.

Smallman, M., 2020. 'Nothing to do with the science': how an elite sociotechnical imaginary cements policy resistance to public perspectives on science and technology through the machinery of government. Soc. Stud. Sci. 50 (4), 589–608. https://doi.org/10.1177/0306312719879768.

Stirling, A., 2008. "Opening Up" and "Closing Down" power, participation, and pluralism in the social appraisal of technology. Sci. Technol. Hum. Values 33 (2), 262–294. https://doi.org/10.1177/0162243907311265.

Strand, R., 2002. Complexity, ideology, and governance. Emergence 4 (1–2), 164–183. https://doi.org/10.1080/15213250.2002.9687743.

Svarstad, H., Benjaminsen, T.A., Overå, R., 2018. Power theories in political ecology. J. Political Ecol. 25 (1), 350–363. https://doi.org/10.2458/v25i1.23044.

Turnhout, E., 2019. Environmental experts at the science-policy-society interface. In: Turnhout, E., Tuinstra, W., Halffman, W. (Eds.), Environmental Expertise. Connecting Science, Policy and Society. Cambridge University Press, Cambridge, UK, pp. 222–233.

Turnpenny, J., Jones, M., Lorenzoni, I., 2011. Where now for post-normal science?: A critical review of its development, definitions, and uses. Sci. Technol. Hum. Values 36 (3), 287–306. https://doi.org/10.1177/0162243910385789.

Urbinatti, A.M., Dalla Fontana, M., Stirling, A., Giatti, L.L., 2020. 'Opening up' the governance of water-energy-food nexus: towards a science-policy-society interface based on hybridity and humility. Sci. Total Environ. 744, 140945 https://doi.org/10.1016/j.scitotenv.2020.140945.

White, S., 2011. Auto-ethnography as reflexive inquiry: the research act as self-surveillance. Qualitative Research in Social Work. SAGE Publications Ltd, London.

Wittmayer, J.M., Schäpke, N., 2014. Action, research and participation: roles of researchers in sustainability transitions. Sustain. Sci. 9 (4), 483–496. https://doi.org/10.1007/s11625-014-0258-4.

Wittmayer, J.M., de Geus, T., Pel, B., Avelino, F., Hielscher, S., Hoppe, T., Mühlemeier, S., Stasik, A., Oxenaar, S., Rogge, K.S., Visser, V., Marín-González, E., Ooms, M., Buitelaar, S., Foulds, C., Petrick, K., Klarwein, S., Krupnik, S., de Vries, G., Wagner, A., Härtwig, A., 2020. Beyond instrumentalism: broadening the understanding of social innovation in socio-technical energy systems. Energy Res. Soc. Sci. 70, 101689 https://doi.org/10.1016/j.erss.2020.101689.

Wye, L., Cramer, H., Carey, J., Anthwal, R., Rooney, J., Robinson, R., Beckett, K., Farr, M., le May, A., Baxter, H., 2019. Knowledge brokers or relationship brokers? The role of an embedded knowledge mobilisation team. Evid. Policy J. Res. Debate Pract. 15 (2), 277–292. https://doi.org/10.1332/174426417×15123845516148.

Wynne, B., 1992. Misunderstood misunderstanding: social identities and public uptake of science. Public Underst. Sci. 1 (3), 281–304. https://doi.org/10.1088/0963-6625/1/3/004.

Wynne, B., 2003. Seasick on the third wave? Subverting the hegemony of propositionalism: response to Collins & Evans (2002). In: Social Studies of Science, 33, pp. 401–417.

Young, J.C., Waylen, K.A., Sarkki, S., Albon, S., Bainbridge, I., Balian, E., Davidson, J., Edwards, D., Fairley, R., Margerison, C., McCracken, D., Owen, R., Quine, C.P., Stewart-Roper, C., Thompson, D., Tinch, R., Van den Hove, S., Watt, A., 2014. Improving the science-policy dialogue to meet the challenges of biodiversity conservation: having conversations rather than talking at one-another. Biodivers. Conserv. 23 (2), 387–404. https://doi.org/10.1007/s10531-013-0607-0.