Science-policy interplay on air pollution governance in China

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Abstract

Air quality in China is a major public health, social and economic concern. Air pollution governance and research in China have been increasingly active in the past decade, especially since 2013 when strict emission controls were implemented. Such emission control policies have been informed through dialogue between scientists and policy-makers on the sources and transport of air pollution in order to identify potential control measures. However, the process of making regulatory decisions about air pollution controls at this science-policy interface in China has rarely been analysed or discussed. We outline four classical science-policy models for making regulatory decisions proposed by scholars: (i) the decisionist model – whereby policy dictates what science and regulatory decisions are required; (ii) the technocratic model – where science dictates policy directly; (iii) the inverted decisionist model (where scientists advise policy-makers on what policy is required); and (iv) the co-evolutionary model (where policy-makers and scientists jointly create regulatory decisions). Boundary-actors play a key role in this co-evolutionary model. They operate as 'gate-keepers' between scientists and policy-makers. Most contemporary studies of the science-policy interface argue that the co-evolutionary model best captures the reality of how science and policy interact effectively to make regulatory decisions. To assess which of these models most closely resemble decision-making at the air pollution science-policy interface in China, we conducted a case study on "air quality climate services" and held workshops with Chinese scientists, decision-makers and stakeholders. A typology of existing scientific approaches to explore air quality climate science is presented. The workshop results show that the current air quality climate science-policy interplay occurs most strongly in accordance with the co-evolutionary model whereby the Beijing Climate Centre and the National Environmental Monitoring Centre operate as the key boundary actors between science and policy, specifically for a seasonal air pollution haze outlook service. We illustrate that current seasonal haze outlooks carefully avoiding quantification. We then present a conceptual framework of the air pollution science-policy interface in China, which captures the main participants and the interactive flow of information between them.

Key words: air pollution; governance; science-policy interplay; conceptual framework; China

1. Introduction

In the past decade, severe air pollution has become a major health, social and economic concern in many parts of the world, especially in low- and medium-income countries (Global Burden of Disease, 2016). In 2010, exposure to ambient particulate matter (PM) was the fourth risk factor for disease burden in China (Yang et al., 2013). In 2013, particularly severe air pollution episodes occurred in Beijing and other Chinese cities (e.g. Wang et al. 2014); and in the same year PM pollution was estimated to be responsible for 1.6 million premature deaths and 1.7 trillion USD (2011) total welfare loss in China (World Bank and Institute for Health Metrics and Evaluation, 2016).

In order to improve air quality and protect public health, the State Council of China issued the Air Pollution Prevention and Control Action Plan (APPCAP) in 2013 to reduce air pollution with goals to be met in five years (Zhang et al., 2016). The goals are further distributed to provincial and municipal governments and senior officials are responsible for meeting the goals (Wong & Karplus, 2017). The APPACP focuses on improving air pollution monitoring, air pollution simulation and prediction and taking emission control actions to prevent and reduce severe air pollution, thereby reducing associated health impacts (Cai et al., 2017; Zheng et al., 2017). Temporary actions to reduce emissions rapidly, such as closing industries with high emissions, reducing car use through driving restrictions and stopping construction works, were issued during big events such as the 2008 Beijing Olympics and the 2014 Asia-Pacific Economic Cooperation meeting (Rich et al., 2012; Tang et al., 2015). Some scientists suggested that in order to improve long-term air quality, China has to transit to a more sustainable economy rather than relying on temporary emission reduction actions, and that this requires more collaboration between scientists, governmental departments, industries and the public (Feng & Liao, 2016; Gao et al., 2017).

Discussion on the environmental science-policy interplay has been ongoing for nearly three decades (McNie, 2007), in fields such as ecosystems and natural resources (Berry et al., 1998; Kemmis, 2002), water (Rayner et al., 2005; Rice et al., 2009), and climate (Dilling and Lemos, 2011; Lemos et al., 2012; Bruno Soares & Dessai, 2016). For much of the 20th Century, managing environmental problems were perceived as being led *either* by policies inspired by specific sets of political values (Young, 2002) *or* by the scientific community. An example of the former is the decisionist model proposed by Max Weber (Van Zwanenberg & Millstone, 2005), while the technocractic model (Weingart, 1999) and the inverted decisionist model are examples of the latter (Van Zwanenberg & Millstone, 2005). More nuanced understanding developed with Haas' (1992 & 1997), concept of the 'epistemic community' as being integral to environmental policy development: a community of scientists and technical advisors emerges around a set of interrelated knowledge claims and associated methods and this becomes intermingled with specific environmental policy activities.

Such thinking paved the way for the emergence of the co-evolutionary model which rejects the assumption that interests are rigidly fixed, and that knowledge and understanding are static and independent of policy. The co-evolutionary model instead conceives of a dynamic interplay between, and emergence of, new knowledge, policy applications and opportunities (Jasanoff, 1987; Lemos & Morehouse, 2005). These models will be introduced in detail in Section 2.

While some analysis of the science-policy interface as it applies to air pollution in Europe and America has been undertaken (Totlandsdal et al., 2007; Lidskog & Sundqvist, 2011; Allen, 2017; Gallardo, 2018), this is much less the case in China (Sheng & Ahlers, 2019). Scientific institutions in China provide air quality information to the government and much air quality research is directly policy-relevant, so examination of the science-policy interface in China is important.

The objective of this paper is to discuss the science-policy interface for air pollution governance in China with empirical evidence from workshops with decision-makers and stakeholders in China and give further suggestions. We discuss classical science-policy interplay models in Section 2. In Section 3, we provide a case study of the "Air Quality Climate

Services (AQCS) Scoping Study in China" drawing on evidence from workshops with decision-makers and stakeholders in China. The AQCS is a project under the Climate Science for Services Partnership, a collaboration between the UK Met Office, the China Meteorological Administration and the (Chinese) Institute of Atmospheric Physics. In the case study, we investigate what are the current scientific methods in providing air quality information on seasonal (and beyond) time-scales, and how scientists and decision-makers in China interact with each other in generating and using such information. In Section 4, we construct a conceptual framework to reflect the air pollution science-policy interplay based on empirical evidence from the workshops and that, we argue, has some potential utility. Finally, in Section 5, we discuss the role of the media as a boundary actor and present some suggestions for further research.

2. Classical models of the science-policy interface

There has been much discussion of the science-policy interface, both theoretical and empirical. Four main models of the interplay of science-policy have arisen from studying the role that scientific evidence and advice does, can and should play in the policy-making process as shown in Figure 1 (Van Zwanenberg & Millstone, 2005).

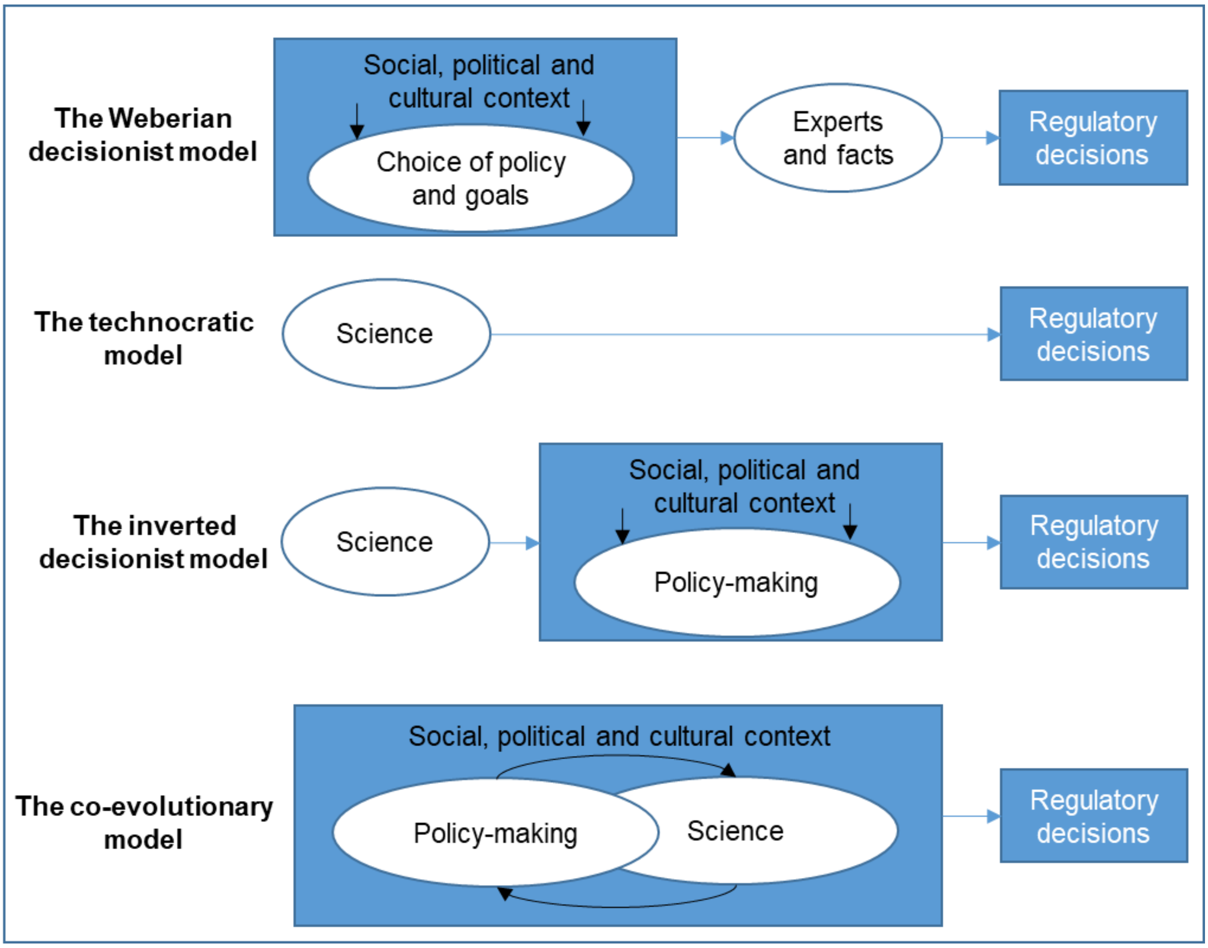

Figure 1. The conceptual structures of the theoretical models about science and governance (Van Zwanenberg & Millstone, 2005).

The decisionist model depicts that regulatory decisions should only be framed by policy goals and objectives. Technical experts are, typically, heavily involved in advising civil servants and politicians as well as in designing and implementing policy, but policy-making cannot be decided by ‘facts’ alone because the underlying objectives of the policy arise from subjective values (Van Zwanenberg & Millstone, 2005). The decisionist model helps explain the process of making some policies on air pollution control in China. For example, although air pollution had been highlighted as a severe problem since the 1990s by researchers in Beijing, air pollution control was not a priority for decision-makers in China. This changed when Beijing was selected to host the 2008 Olympic Games and China was faced with concern from international governments about athletes’ health (Hao & Wang, 2005; Streets et al., 2007). The Beijing municipal government adopted a decisionist model by announcing the “Air Quality Guarantee Plan for the 29th Olympics in Beijing”. As a result, strict emission controls were implemented, leading to improved air quality during the Games (Wang et al., 2010).

By contrast, policy-making in the technocratic model and the inverted decisionist model are both driven by science. The technocratic model claims that policy should be based on, and only on ‘sound science’ (Weingart, 1999) and it assumes that science and facts are totally objective, socially and politically neutral and are ready to be turned into policy (Van Zwanenberg & Millstone, 2005) The main critique of this approach is that it struggles to incorporate the role of ethical values in determining human affairs. According to the inverted decisionist model, scientists identify the goals of regulatory decisions and policy-makers are confined to deciding the most appropriate policies to reach the science-derived targets (Van Zwanenberg & Millstone, 2005). For example, it was scientific evidence on the contribution of volatile organic compounds (VOCs) to high levels of ozone pollution over the North China Plain (Tang et al., 2012), that resulted in the Ministry of Ecology and Environment issuing an Action Plan on VOCs Control and Prevention (MEE, 2017).

However, scholars across many technical policy arenas have challenged the ‘linear’ model of the science-policy interface and the separation of ‘science’ from ‘policy’ and proposed the co-evolutionary model (Jasanoff, 1987; Lemos & Morehouse, 2005). Empirical research identified certain scientists who spend long periods of time with policy-makers and come to absorb policy objectives and priorities. Their scientific advice ceases to be entirely based on scientific knowledge and understanding but is also partly shaped by their recognition of policy objectives and constraints. These policy choices are frequently used to ‘plug gaps’ in the scientific argument that emerge due to uncertainties. Those policy-makers who interact closely with scientists also absorb understanding of scientific constraints and uncertainties, hence their proposals cease to be based on political preferences alone. They use scientific arguments to ‘plug gaps’ in the policy case which exist due to the imprecision of policy formulation. Such ‘mutual construction’ of science-for-policy may evolve through selective pressures (fit between the constraints of scientific understanding and policy objectives and priorities) such that, over time, a co-evolutionary relationship arises. A network of professionals with shared beliefs are seen as an epistemic community (Haas, 1992). Through the interaction of the epistemic community with policy-makers, their science becomes effective and powerful in shaping international policies. The epistemic community is a key concept towards the development of the co-evolutionary model.

Boundary-actors (also known as boundary-spanners) play a very important role in the ‘negotiation’ between science and policy. Boundary actors are institutions or individuals at governmental departments, consultancies, non-governmental organisations and research institutes who span the boundary between science and policy and provide dedicated translational services that facilitate the communication between scientists and policy-makers, such as integrating, translating and transferring scientific information, understanding and transferring policy needs, and operating as ‘gate-keepers’ to control what policy discourse gets through to scientists and vice versa (Jasanoff, 1987; Shackley & Wynne, 1995). Boundary actors mediate between the science and policy communities, producing information and outputs that are useful for both and enhance the usability of scientific output in policy decision-making; they are the means by which co-evolution occurs (Moser & Cash, 2000; Agrawala et al., 2001; Guston, 2001; White et al., 2010).

Most contemporary studies of the science-policy interface argue that the co-evolutionary model best captures the reality of how science and policy interact effectively to make regulatory decisions (e.g. Lemos, & Morehouse, 2005; Golding et al., 2017; Gallardo, 2018). The co-evolutionary model is partly empirical (what happens) and partly normative (what should happen).

An example of the co-evolutionary model is the development of the World Health Organisation's (WHO) Air Quality Guidelines (AQG) and the Chinese National Ambient Air Quality Standards. The WHO gathers epidemiological evidences about the adverse health effects following the exposure to ambient Particulate Matter less than 2.5 aerodynamic micrometres (μm) in diameter ($PM_{2.5}$), but research has not identified thresholds below which adverse effects do not occur. Considering existing scientific evidence, public health priorities and the constraints and capabilities in reducing $PM_{2.5}$, the WHO set AQG of $PM_{2.5}$ as 10 μgm^{-3} for annual mean and 25 μgm^{-3} for 24-hour mean (WHO, 2005). The WHO suggested each country establish its own national standards balancing health risks and national specific factors giving suggested interim goals. In 2012, the Chinese National Ambient Air Quality Standards were amended to include standards for $PM_{2.5}$ (Table 1). By providing flexibility in the standards that a nation adopts, in recognition of economic costs and other constraints, it can be argued that the co-evolutionary model is at work here.

Table 1. The Chinese National Ambient Air Quality Standards for $PM_{2.5}$ (MEE, 2012).

Average over defined time period	Grade I (μgm^{-3})	Grade II (μgm^{-3})
Daily	35	75
Annual	15	35

Some scholars have observed that the co-evolution of science for policy can lead to the uncritical adoption of policy objectives by scientists and, likewise, the uncritical adoption of scientific understanding by policy-makers. In this case, an elite of policy-makers and their advisory technical experts takes the place of the technocracy. On the other hand, promoting dialogue between scientists and policy-makers must be desirable when formulating science-based and technical policy; the issue is how to enable an appropriate dialogue that protects against premature closure of either the science or policy decisions because a technocratic elite finds that it is 'convenient' to do so. Therefore, caution is also needed when performing a co-evolutionary model and we should be careful not to assume that a science-policy interplay corresponding to the co-evolutionary model is superior to other 'linear' models in the situations where we neglect the details of how they are operated.

3. Case study – Air Quality Climate Services

The Air Quality Climate Services (AQCS) Scoping Study engages scientists and decision-makers in China to ascertain: (i) the current state of air quality science and (ii) how scientists and decision-makers interact with each other in generating and using such information. In this paper, 'air quality climate science' means the interaction between air pollution and climate, and the forecasting, predictions and projections of them on seasonal and beyond timescales. Meanwhile, 'air quality climate service' means making use of air quality climate science in decision-making. Currently, air quality climate science and services are very much in development and this case-study provides material for examining the emergence of a novel science-policy interface, both globally and in China.

3.1. State of science in the air quality climate space and challenges

To better understand the interaction between science and policy in the air quality climate service in China, we first attempt to understand the state of the science in air quality climate science. Understanding of the complexity of these scientific domains is necessary to comprehend the challenge of effective interaction between science and policy.

To do this, we held a one-day workshop with scientists working in the interdisciplinary area of climate and atmospheric sciences. There were thirty scientists from leading Chinese universities and research institutes including Beijing Climate Centre, Chinese Research Academy of Meteorological Sciences, Beijing Normal University, Institute of Atmospheric Science, Nanjing University, Peking University, and Tsinghua University.

The workshop with scientists found that a heterogeneous set of methods are employed in air quality climate science as shown in Figure 2. Both process-based models and statistical models are used in studying the air quality climate science. It is noteworthy that much research was performed from a statistical perspective where meteorological variables were linked to air quality. Statistical techniques to derive air quality commonly took the form of multivariate analyses including multiple linear regression but also a neural network approach in one study. A few studies used meteorological reanalyses to drive a chemistry transport model. Several studies used chemistry-climate models where a chemistry transport model was coupled to a climate model. In choosing which of the methods in Figure 2 to select, scientists and users weigh-up the benefits and disadvantages of computationally intensive coupled chemistry-climate modelling versus statistical estimation from reanalyses and climate model output which is computationally-light.

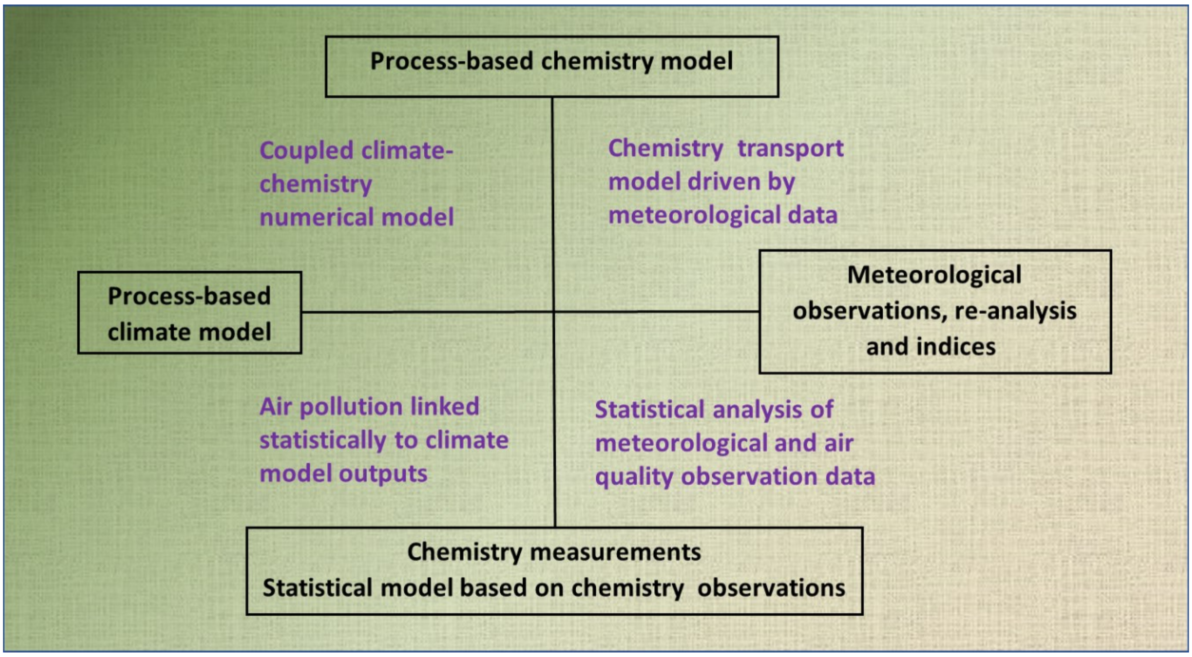

Figure 2. Method classification of approaches used by workshop participants in studying air quality climate science.

Studies of air quality that use chemistry transport models driven by reanalysis or chemistry-climate models need to use representative emissions inventories. Obtaining reliable emissions inventory data is a major challenge. Two commonly used inventories for China are TRACE-P

(2008) and MEIC (http://www.meicmodel.org/) but many other inventories exist. An inaccurate emission inventory leads to uncertainties in air pollution forecasts.

A lack of long-term air quality observations for evaluating air quality models is another limitation since the Government's obligation for monitoring has only been established relatively recently. The systematic monitoring of $PM_{2.5}$ only started in 2013 undertaken by the Ministry of Ecology and Environment (MEE). There are also no official archives of air pollution data open to researchers and the public from the MEE website, hampering monitoring and model evaluation in relation to climate influences on air quality.

The heterogeneity in the methods in studying air quality climate science likely indicates the novelty and high uncertainty of the domain and argues against closure at this stage around any one approach and method. The next section explores the nascent science-policy interplay in this technical arena.

3.2. Science-policy interplay on seasonal haze outlook service

In order to understand how scientists and decision-makers interact in air quality climate services, we held five separate workshops with the technical supporting institutes of the MEE, the major authority in charge of air pollution governance in China, and decision-makers in local Meteorological Services and Bureaus of Ecology and Environment. The China Meteorological Administration (CMA) and the UK Foreign and Commonwealth Office in China helped in the identification and recruitment of workshop participants.

It was found that Beijing Climate Centre (BCC) of the CMA started producing seasonal outlooks for weather conditions related to the diffusion of air pollution ('haze' for short) since winter 2017 in collaboration with the China National Environmental Monitoring Centre (CNEMC) of the MEE (MEE, 2018). The haze outlook report is provided to the MEE and local Meteorological Services. BCC and CNEMC act as the major boundary actors between scientists and decision-makers in providing this winter haze outlook service (Figure 3). CNEMC is an affiliated institution of the MEE for air pollution monitoring and forecasting and BCC provides support in climate forecasting. BCC has a team of climate scientists and forecasters, who conduct research and produce operational climate forecasts and who work closely with scientists from other institutes such as the Institute of Atmospheric Physics (IAP) and also decision-makers, notably those at the MEE. Experts at BCC conduct analysis including calculating an index on Atmospheric Self-Cleaning Ability and an East Asian Winter Monsoon index which is then correlated to winter haze. These are in-house statistical methods that enable BCC to gain rapid insight into seasonal and climate impacts on weather and haze. Forecasters at BCC and CNEMC discuss the various strands of evidence on a monthly basis and it is increased to 1-2 times/week before winter when the air pollution is expected to be worse than in other seasons. The Chief Forecaster produces a final judgement and evidence based seasonal haze outlook which is provided to decision-makers at the MEE, then released to the public.

This report is consisted of qualitative statements regarding the potential impact of seasonal weather on haze and the air quality, such as "the atmospheric circulation is adverse to the diffusion of the air pollution and polluted days will be near the 3-year average level" (MEE, 2018). The Chief Forecaster is careful to avoid quantitative statements at this stage due to the high uncertainty in the science and the risk of misleading users if a spurious level of quantitative accuracy was presented.

The seasonal air pollution outlook is assumed to support the MEE in making decision in two ways: ① making reasonable air pollution targets, which considers both public health and the feasibility in achieving the target; ② planning emission control actions in advance such as shutting up certain factories in order to achieve a certain level of air quality to protect public health.

The MEE has very close interactions with BCC in discussing and understanding haze conditions in the next season especially before winter. For example, the director of the Air Division at the MEE led his team to visit BCC twice in November 2019 to discuss haze conditions in the coming winter. The MEE also sends requests to BCC and asks for its feedback on various issues. For example, researchers at BCC stated that their team was asked by the MEE to provide a 2 to 3-year air pollution outlook in support of making air pollution reduction plans. The MEE also feeds back to BCC on the performance of its seasonal haze outlook because the MEE owns the observational data to enable evaluation of the forecast.

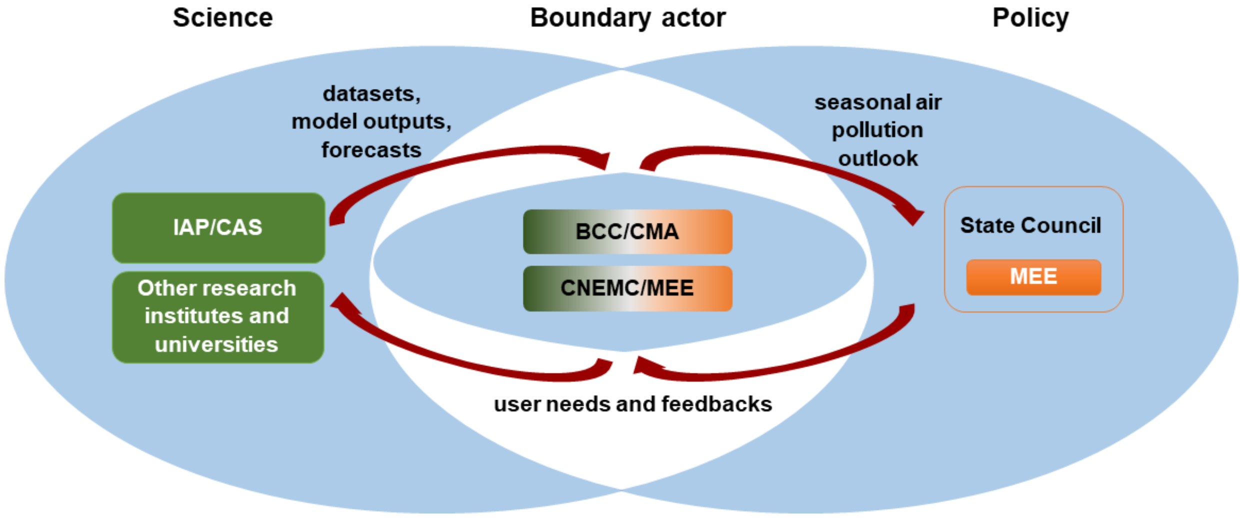

Figure 3. The science-policy interplay for the seasonal haze outlook service. IAP/CAS: Institute of Atmospheric Physics of Chinese Academy of Sciences; BCC/CMA: Beijing Climate Centre of China Meteorological Administration CNEMC/MEE: China National Environmental Monitoring Centre of Ministry of Ecology and Environment.

The workshop results indicated that the current air quality climate science-policy interplay occurs largely in accordance with the co-evolutionary model (Figure 1). The relationship between air quality and climate is being driven by both scientists and decision-makers and boundary actors, i.e. BCC and CNEMC, are identified which facilitate the interplay (Figure 3). The boundary actors are exercising considerable judgement in managing the boundary between air quality, seasonal forecasting/climate and avoiding premature closure of either the scientific or policy options. In other words, the boundary actor is avoiding selecting the most appropriate scientific methods for relating weather, climate and air quality given existing uncertainties; it also appears to avoid defining the policy needs too narrowly at this juncture.

Although the classical linear models explain the science-policy interplay for some regulatory decisions (Section 2), the co-evolutionary model is more perspicuous in the case of air quality climate services due to the uncertainty and complexity of both the emergent science and policy development.

4. A conceptual framework for air quality science-policy interplay

On the basis of the empirical workshops, we construct a conceptual framework for air quality science-policy interplay in Figure 4 that is designed to reflect the science-policy interplay in China in air pollution governance. The conceptual framework is constructed based on empirical results from the workshops as discussed in Section 3, and normative speculations based on existing discussion on the science and policy interplay in the literature on co-evolution (Jasanoff, 1987; Lemos & Morehouse, 2005; Van Zwanenberg & Millstone, 2005). In this section, we indicate where we draw upon more speculative concepts and ideas through using appropriate modal verbs ('could') and adverbs ('sometimes').

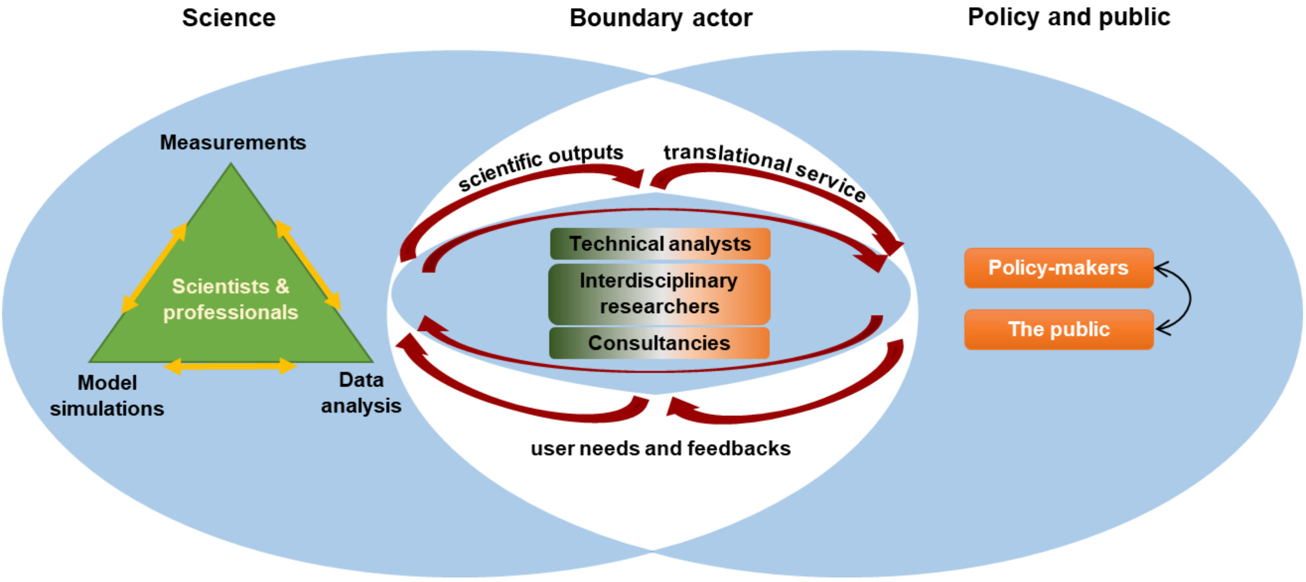

Figure 4. A conceptual framework for air quality science-policy-public interplay.

Scientists conduct activities such as monitoring or making measurements, data analysis e.g. for source apportionment, and air quality modelling using statistical or process-based numerical models. They then generate outcomes in the form of datasets e.g. air quality indices, model outputs, forecasts or projections. Boundary actors include technical analysts at governmental institutions and other analysts who make use of air pollution outputs in policy analysis based in public and research institutions, or consultancies.

Translational services providing user-specific information mainly flow from the boundary actor but could also flow directly from the scientific community. The governance of air pollution involves policy-makers, and sometimes the public, whose health and daily life activities are affected by the air pollution.

The MEE is the only authority that is allowed to provide air pollution forecasts to the public, which can be accessed from TV weather broadcasts, websites, social media (e.g. WeChat) and portable devices apps such as Blue Map and Air Matters. With air pollution information, the public can be made more aware of the health impact of air pollution and take corresponding health protection measures such as reducing outdoor exercises and wearing face masks at times of heightened risk. There are also methods by which the public could give feedback to policy-makers. Indicated by a participant from Shanghai Environmental Monitoring Centre (SEC), there is a hotline by which the public can phone SEC to put forward enquires. Speculatively, the public could interact with the boundary actors and the scientific community through long-distance communications such as e-mail, comment box, survey and public engagement workshops. However, it is unknown to what extent the public could influence regulatory decisions on air pollution governance in China.

The role of an institution as a scientific information provider, boundary actor or using scientific information in making decision depends on the particular service and situation, which can vary from case to case. Taking the MEE as an example, on one hand, the MEE is a user of air quality climate services as discussed in Section 3.2; on the other hand, the MEE is also a boundary organization for public air quality services. The MEE receives forecasts from a range of sources, including air pollution monitoring and near-term forecasts from CNEMC, weather forecasts from the CMA and numerical model outputs from the Institute of Atmospheric Physics. The MEE integrates all the information together than provides easily understood air quality information to the public, such as Air Quality Index (AQI) levels indicating the severity of air pollution for the next 24 to 72 hours and severe haze warnings.

Although the conceptual framework is constructed based on empirical evidence in China, it can also be applied to other countries because normative speculation based on existing literature is integrated into the framework. The conceptual framework is useful for ① boundary actors and decision-makers who want to improve air pollution governance by increasing the effectiveness of science-policy interplay; ② applied scientists who want to improve the usefulness and uptake of scientific information by decision-makers; ③ those who want to identify and characterise the main participants in air pollution governance and the main information flows and interplays.

5. Discussion

Most analyses and discussions of the science-policy interface have taken place in the OECD 'western' countries – Europe, North America, Australia, etc. Much less is currently known about how the science-policy relationship is developing in China. This paper uncovers evidence that the science-policy interface in China in the emerging domain of Air Quality Climate Services displays familiar features that correspond with the co-evolutionary model. Boundary-actors play a key role in enabling air quality climate science and policy to become interrelated.

Boundary actors such as Beijing Climate Centre and National Environmental Monitoring Centre conduct technical analyses themselves as well as aggregating research outputs from other research institutes and universities. They assemble highly complex scientific outputs into outputs that can be utilised by policy-makers in creating new potential services to users. Both the science and policy co-evolve as boundary actors provide up-to-date scientific evidence to policy-makers and policy-makers actively seek out scientific information and its interpretation from boundary actors.

Air quality climate science is an emerging area with a variety of research methods and high technical uncertainties. The co-evolutionary model captures the emerging dynamics between uncertain and fast evolving science and policy expectations, in a way that eludes the other models discussed in Section 2 because these other models are only effective in a short-term, pre-suppose policy needs or else require scientific knowledge with a high level of certainty.

Very similar dynamics between uncertain science and evolving policy are observed in the 'west', however, there are differences as well. For example, senior policy-makers in China appeared to have higher relevant technical degree qualifications and could be characterised as technocrats, e.g. the Director of the Air Division of the Ministry of Ecology and Environment was a post-doctoral researcher in environmental management at Harvard University. As a generalisation, senior policy-makers and politicians in the UK tend to be 'generalists' rather than technical specialists. Such policy-makers and politicians in the UK are supported by technical specialists, either within Government or in consultancy firms and universities. More research is required, however, to verify this speculation, for instance by investigating the qualifications and backgrounds of a range of civil servants in China and western countries.

Although the case study on Air Quality Climate Services in China shows that the co-evolutionary model best reflects the emerging science-policy interplay on seasonal haze outlook services, adopting the co-evolutionary model does not necessarily mean a decision-making process is automatically effective. Lemos et al. (2012) state in a review study that even in the situation where policy-makers are actively seeking information from scientists and scientists are producing useful outputs, there is still likely to be a usability gap of climate information. Key factors required in reducing the usability gap include iterative interactions, focused relationships, building relationships at an early stage and establishing ongoing relationships (Reed, 2008; Lemos et al., 2011; Golding et al., 2017).

In the conceptual model, we did not emphasise the role of the media, while it may be seen as a boundary actor as well especially for the public. The media makes knowledge accessible and understandable by translating technical jargon, reducing complex statistical information and details on the research process (Scharrer et al., 2016). There is empirical evidence that newspaper articles largely reflect the claims made in scientific journals (Brodie et al., 2003; Bubela & Caulfield, 2004; Krauth & Apollonio, 2015). However, scientific information reported by the media can be inaccurate and misleading because it changes the emphasis of technical detail, omits relevant information, de-emphasises uncertainties and dramatises the findings (Singer, 1990; Brechman et al., 2009). Therefore, media can be a useful channel where the public obtain scientific information, whereas caution is required. We suggest more studies about the role of the media in air pollution governance in China.

This paper mainly discussed the interplay between science and policy, and only briefly discussed the role of the public. It is the public who are most affected by regulatory decisions and understanding public perceptions could also help in making better policy that reflects societal needs and allows more effective implementation (Irvin & Stansbury, 2004; Dickson et al, 2012). To what extent the public interacts with scientists and decision-makers in making regulatory decisions and the suitable method by which this interaction is enabled will vary country by country and case-by-case (Hering et al. 2014). Therefore, we suggest another fruitful area of research about the perceptions of the Chinese public vis-à-vis air quality and the impact of weather and climate. This study could also include the methods for integrating public opinions and receiving public feedback into air pollution decision-making in China and the effectiveness of these methods. This paper mainly focuses on the national level in China, but we recognise that the international epistemic community may have an important role in the science-policy interface on air pollution governance, which is another interesting future research area.

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