A Rationale for Science-Policy Interfaces

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Abstract

This paper aims at a better understanding of the justifications for science-policy interfaces, of the reasons for their growing importance in environmental governance, and of the theoretical and epistemological challenges they pose. We look at the intersections between science and policy to highlight that science and policy, far from being mutually exclusive and hermetic categories, are intersecting domains of human activities which are in co-evolution. Science-policy interfaces are defined as social processes which encompass relations between scientists and other actors in the policy process, and which allow for exchanges, co-evolution, and joint construction of knowledge with the aim of enriching decision-making. They are implemented to manage the intersection between science and policy. The theoretical questions which arise at this intersection are then explored, which allows for the identification of a series of fifteen normative requirements for science-policy interfaces. The conclusion suggests that this normative content may provide guidance for the design, implementation, and evaluation of real-life science-policy interfaces, and identifies key methodological issues which need further theoretical research as well as practical experimentation.

Keywords

Science-policy interfaces; post-normal science; environmental governance.

1 Introduction

The objectives of this paper are to clarify the concept of science-policy interfaces, to propose a definition thereof, to explore theoretical issues raised by these processes and to extract some normative requirements for their design and implementation.

In the field of environmental governance, the search for going beyond a naive vision of the relations between science and policy as two independent monologues which intermittently exchange products takes place at all levels. The concept of post-normal science as developed by Funtowicz and Ravetz (1993, [1, 2] represents a major advance towards a different understanding of science and in particular its relations with policy. Reflections and experimentations on the design of processes for developing effective relations between the realms of science and policy are flourishing. At the local level, policy-makers and managers

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from both public and private institutions constantly innovate on new forms of interaction between science and decision-making. On the European scene, the need for more research on, and analysis of existing experience with, science-policy interfaces is recognised notably in the Sixth Framework Programme for Research and Technological Development of the European Union (FP6), which calls for more systematic examination of the various components of *'science and governance'* and in particular for*: "developing appropriate means for creating scientific references and channelling scientific advice to policymakers and equipping policy-makers with tools to assess and manage scientific uncertainty, risk and precaution"*; for new consultations mechanisms in this regard; and for assessing the *"interaction between experts, industry, civil society and policy-makers"*. [3] Many research projects are striving to reinforce their interface with policy and networks which aim in particular at improving the overall European science-policy interface are set up.[1] At the international level, processes like the Intergovernmental Panel on Climate Change (IPCC) [7, 8] or the current debate on the need for an International Mechanism of Expertise on Biodiversity [9] are illustrations of practical implementation of science-policy interface processes. Meanwhile, research on the topic is taking off, as exemplified by the work of the Harvard-based Global Environmental Assessment Project which aims at understanding the role of organized efforts to bring scientific information to bear in shaping social responses to large-scale global environmental change. [10, 11, 12] Hence science-policy interfaces are rapidly emerging as key elements of environmental governance.

The current burst of activity on and around science-policy interfaces does not occur out of an intellectual void. It strongly builds on long-lasting philosophical, sociological and political questions about the roles of science in society and in particular on crucial research and debates in the fields of philosophy of science, epistemology, sociology of science, science studies, futures studies, risk studies and their many developments.

It is with a transdiciplinary perspective inspired by numerous authors from these fields that this paper attempts to answer three questions: (i) What are science-policy interfaces? (ii) Why do they exist? and (iii) How should they operate? In Section 1, I look for the domains of intersection between science and policy. Because the underlying rationale for this paper is to understand the role of science in environmental governance, the heuristic path used is to start from the science side. A series of theoretical problems arise at those domains of intersection and the relation between science and policy must be managed to address these problems. This is the raison d'être for science-policy interfaces. These theoretical problems are explored in Section 2 which allows for the identification of a series of normative requirements for science-policy interfaces. The result is a series of fifteen such requirements, organised along problems relating to outputs, processes, actors and context of science. Throughout the paper I touch upon a number of aspects of science, such as complexity, uncertainty and indeterminacy, and some particularly important distinctions such as those between issue-driven and curiosity-driven science, explanation and predictions, objective and subjective knowledge. These journeys allow for a more precise identification of the nature of science-policy interfaces and justify the normative requirements which are proposed. They also aim at widening up the debate on science-policy relations, which in practice still very often builds on an underlying understanding of science as an isolated and deterministic system producing value-free truths. The conclusion proposes an answer to the three questions above and suggests avenues for future research on science-policy interfaces.

Although the focus is theoretical, the reflection presented here builds extensively on hands-on experience with real-life science-policy interfaces. In particular, the case of the European Platform for Biodiversity Research Strategy (EPBRS) [13], the review of the science-policy interfaces of a series of European biodiversity research projects [14], the science-policy

[1] As illustrated for instance by the EPBRS for the interface between biodiversity science and biodiversity policy [13], the AIRNet thematic network on air pollution and health [4], the AlterNet and Marbef Networks of Excellence [5, 6] and many others.

interface of the HERMES project on deep sea ecosystems [15], science-policy interfaces in the case of radioactive waste disposal [16, 17], and the EC Research/Policy Interface for Kyoto and Beyond project [18, 19].

2 Science and policy: intersections and co-evolution

In this section, I explore the domains of intersection between science and policy by asking the questions: "What, in the nature of science, creates an intersection with policy?" and "How is science linked to political action?" According to Richard Feynman, in everyday language 'science' usually means a special method of finding things out, a body of knowledge, the new things one can do with what has been found out (that is, technology), or a mixture of these meanings. [20] But science is also a social process, set in a social context, and involving actors and institutions. These multiple facets of 'science' suggest that, when searching for the domains of intersection between science and policy, we successively look at the outputs of science, its processes, its actors and its context.

2.1 Outputs of science

The foremost and most obvious domain of intersection between science and policy relates to the fact that scientific knowledge is a very common ingredient of policy making, and science is often called upon to provide solutions to societal problems. One of the main reasons for this situation relates to the exponential development of science and technology and the emergence of environmental and societal side-effects which extend over unprecedented broad spatial and temporal scales and are often irreversible. [21, 22]

But what knowledge are we talking about? To answer this question, an exploration of the outputs, aim and purpose of science may be helpful. Science is an activity whose most important output – something Richard Feynman calls the *"yield of science"* ([20], p.9) – is scientific knowledge. But why does science produce knowledge? The fundamental aim of science is to find explanations of the world, or, in Karl Popper's words, *"of whatever strikes us as being in need of explanation"*. ([23], p.191), [24] For Ernest Nagel, "*it is the desire for explanations which are at once systematic and controllable by factual evidence that generates science; and it is the organization and classification of knowledge on the basis of explanatory principles that is the distinctive goal of the sciences."* ([25], p.4). So explanations can be considered as the main yield of scientific activity. Another type of output of science is predictions. These are clearly important as, on the one hand they form part of the characteristic method of science and as such are often useful for developing and selecting good explanations, and on the other hand they can be useful for practical applications of science. Nevertheless, predictions cannot be considered as the ultimate objective of science, they remain in a sense secondary to explanations. In the words of Deutsch: *"Prediction – even perfect universal prediction – is simply no substitute for explanation."* ([26], p.5) The distinction between explanation and prediction is important because some misunderstanding about the nature and role of science – and in particular its relation with policy – probably comes from a lack of recognition of this distinction, as will be discussed in section 2.

Scientific knowledge is not just any kind of knowledge. Popper defines two different types of knowledge or of thought: (1) subjective knowledge, *"consisting of a state of mind or of consciousness or certain inborn dispositions to behave or to react"* ([23], p.108); and (2) objective knowledge, *"consisting of problems, theories and arguments"* (ibid.), *"for example scientific knowledge which consists of conjectural theories, open problems, problem situations, and arguments"* (ibid, p.121). Popper stresses that *"knowledge in this objective sense is totally independent of anybody's claim to know; it is also independent of anybody's belief, or disposition to assent; or to assert, or to act. Knowledge in the objective sense* is knowledge without a knower*; it is* knowledge without a knowing subject.*"* (ibid., 109, emphasis his) Note however that Popper recognises that these objective structures are *“caused by human behaviour”* (ibid., 114), they are human creations. He then stresses the *“intersecting relations”* between these two senses of knowledge; in particular, it is because of the *“interaction between ourselves and the third world* [of objective content of thought (Popper’s World 3)] *that objective knowledge grows.”* (ibid.: 112) He also stresses the *“repercussions, or the feed-back effects, of the evolutions of the third world upon ourselves – our brains, our traditions (…), our dispositions to act (that is our beliefs) and our actions (…)”* (ibid., 122) Objective knowledge should not be mistaken for (unique and univocal) truth. Objective knowledge is produced by science in its *“approximation of (absolute) truth”* (ibid., 126) but it is not equivalent to truth. Objectivity in science *“rests (…) upon the criticizability of its arguments”* (ibid., 137). Hence one could say that the specificity of scientific knowledge is that it pursues an ideal of (some form of) objectivity.

Popper’s distinction between objective (scientific) knowledge and subjective (action) knowledge has to be qualified since in practice scientific knowledge, even though it strives to be objective, is always intertwined with subjective knowledge which is eminently social and political. In other words, science progresses through the co-evolution of subjective and objective knowledge, and the subjective knowledge does not only belong to the realm of science. The combination of objective and subjective knowledge hence appears as a crucial domain of intersection between science and policy.

Hence, science aims at producing objective scientific knowledge to providing explanations of the world and to a lesser degree predictions. But what is the purpose of such knowledge? Knowledge –scientific or not– is often used to guide action because it can provide understanding. However, as stressed by René Thom ([27], p. 32, my translation), there is a difference between understanding and acting: *“But nature is so that understanding and acting are not synonymous... One often understands situations without being able to act: this is the case of the man in a flood who climbs on the roof of his house when water level rises. In other cases one acts effectively without really understanding why.”* So claiming that scientific knowledge is ‘useful’ only insofar as it provides a basis of action is not sufficient. This relates to the long-standing debate between “science for science” (curiosity-driven science) and “science for action” (issue-driven science). Henri Poincarré [28] was a great defender of the former, he stressed that action is not the primary goal of science. For him, if science is useful it is because it is true, it is not because it is useful that science is true. The only goal of science is science: *“One cannot say that action is the aim of science. Must we condemn the studies of Sirius under the pretext that we will probably never exert any action on this star?”* (ibid., p. 155, my translation). Nonetheless, even if action is only a secondary goal of science, some of the knowledge yielded by science is of considerable relevance to action. Scientific knowledge is often called upon and used in the processes of making decisions – including policy decisions – and acting and this creates and intersection with policy. We will come back in Section 2 to the distinction between issue-driven and curiosity-driven science as it poses a problem in relation to the role of science in policy.

To explore the nature of this domain of intersection between science and policy, one may look at how scientific knowledge relates to political practice. Starting more from the nature of modern politics, Habermas [29] distinguishes three models for this relation. In the *decisionistic model* of Max Weber, technical (scientific) knowledge is present but the political choice based on values and beliefs is prevalent. In the *technocratic model*, this dependency between knowledge and politics is inverted and political practice is relegated to the role of executive arm of a scientific intelligentsia. ‘Optimal’ solutions emerge from science and political choice becomes fictive. The *pragmatic model* recognises that there is an interdependence between values and facts: *“For there is obviously an interdependence between values that proceed from interest situations and techniques that can be utilised for the satisfaction of value-oriented needs.”* (ibid., p. 66) In this model, *“the strict separation between the functions of the expert and the politician is replaced by a critical inter-relation.”* (ibid.) It is precisely this inter-relation which creates an intersection between science and policy.

Finally, another domain of intersection stems from the fact that science can contribute to the emergence of issues on the political agenda, by the mere fact of discovering a phenomenon. Examples of this in the environmental field are numerous, such as for instance the emergence of the ozone layer issue following the scientific discovery of ozone depletion caused by anthropogenic emissions of CFCs (see e.g. [30]).

2.2 Processes of Science

Value judgments, including some of an epistemological or methodological nature, are present in any scientific practice. Ulrich Beck ([21], p. 174) describes this in the following terms: *"The prevailing theoretical self-concept of science implies that the sciences cannot make value judgements with the authority of their rationality. The deliver so-called 'neutral' figures, information, or explanations which are to serve as the 'unbiaised' basis for decisions on the broadest variety of interests. Which interests they select, however, on whom and what they project the causes, how they interpret the problems of society, what sort of potential solutions they bring into view – theses are anything but neutral decisions."*

Particularly in the case of issue-driven science, the choice of which domains of scientific knowledge are developed in priority –that is, which problem situations are looked at and which are left aside– involves dynamics which pertain to both the scientific and the policy processes. The identification of the issue, the choice of relevant disciplines, methodologies, scales, variables, and boundaries, and the strategies to articulate them are elements of the scientific process which are in no way isolated from the socio-political context, as is quite obvious in the case of environmental issues. Hence the first domain of intersection between science and policy in relation to the processes of science stems from the fact that the processes of selecting, framing and addressing a scientific problem as well as the design of potential solutions pertain to both the scientific and the political processes.

A second domain of intersection between science and policy in relation to the processes of science exists in the policy area that deals with scientific orientation and funding, which is referred to in this paper as 'science policy'[2]. This domain of intersection has a wider bearing than might be thought at first, because not only does science policy impact on the topics science focuses on, but it also has enormous effects on the way science proceeds and, to the extent that funding agencies stress the importance of dissemination, on the way scientific knowledge diffuses into society in general and into policy processes in particular. The European Community Framework Programmes for Research provide an illustration. They are predicated on Article 163(1) of the Treaty establishing the European Community, which states that: *"The Community shall have the objective of strengthening the scientific and technological bases of Community industry and encouraging it to become more competitive at international level, while promoting all the research activities deemed necessary by virtue of other chapters of this Treaty."* The result is a EU science policy which places priority on (competitive) technological applications and issue-driven science over curiosity-driven science. This has important consequences in terms of which scientific knowledge is available for which policy domain, but also less visibly on the way policy domains are prioritised in Europe.

The third domain of intersection relates to the quality and validation institutions of science. In her analysis of peer review and regulatory science, Sheila Jasanoff ([31], p. 79) shows that: *"Peer review appears not to be the objective, dispassionate process than its advocates represent it to be. Standards of validity in science are also revealed as somewhat fragile constructs that may hold up under friendly scrutiny, but are apt to disintegrate under controversy or critical review. Accordingly, the notion that science-based regulation can be lifted above politics and ideology through peer review appears seriously misguided."* The

[2] Note that Sheila Jasanoff [31] attaches a different meaning to these words, for her 'science policy' is an area of decision-making where science has a role in regulatory proceedings. In this paper, this meaning is captured by our use of policy as we are only concerned by those policy areas where science does play an important role.

important point here is that the very process of scientific validation of issue-driven science belongs both to the scientific process and to the policy process. And although it is often a hidden thing, it should not come as a surprise since when science is to inform policy, divergent stakes and interests are most likely to be present and actors will be tempted (rightfully or wrongfully) to influence the scientific validation process. Hence, as soon as the science at hand is issue-driven, its quality and validation processes also create a domain of intersection between science and policy.

A fourth domain of intersection stems from scientific education and training, as these institutions are not the exclusive realms and under exclusive control of the scientific community. There is a high policy influence on their orientation. But the other way around is also true, as the way scientific education and training is organised in a given country will in turn affect the roles scientists may take in policy processes.

Scientific networks for their part constitute another mechanism by which *"scientists build up their cognitive authority"* ([31], p. 83) and as such form part of the validation process discussed above. Moreover such networks may be organised to be used as a powerful vehicle for channelling scientific input to policy-making. A notorious example is the area of science policy where many professional scientific networks are organised to ensure the presence of their 'pet issue' on the research agenda. This leads to yet another domain of intersection between science and policy.

The four latter domains of intersection identified stem from the institutionalisation of science and of its methods. They correspond to a series of crucial scientific institutions: the organisation and funding of public and private scientific research; the processes aiming at ensuring scientific quality and validation; and the scientific education, training and networking systems. Note that it is because these institutions are unavoidably value-laden that the intersection with the policy process exists. Value choices contribute to orientation of research programmes, they are part of the validation process, they inform the design of education and training systems, and they contribute to the emergence and operations of networks.

2.3 Actors and context of science

The actors of science are primarily the scientists themselves, with their curiosity, values, interests and passions. Scientists can work in an array of different institutions such as universities, public and private research institutes, governmental agencies, private business, NGOs, or they can also work in several of these concurrently or sequentially. Actors of science also include all the persons who one way or another act within the scientific institutions. All of these persons are engaged in relations with different types of institutions. An important intersection between science and policy lies in the role of expert exerted by some scientific actors, where they are called upon – or sometimes self-designated – to feed scientific knowledge to the policy process. Another intersection stems from the different values and interests of the various actors of science, which may drive them towards influencing the policy process in a way that supports their interests.

As for the context of science, it consists of the environment – both natural and social – in which science unfolds. This environment acts upon and constrains science, but science and in particular its results also act upon the (social and natural) environment. There are three intersections between science and policy here. The first is a consequence of the fact that science acts upon the environment, in particular via technology, and this in turns impacts on societies in direct or indirect, positive or negative ways. Such chains of actions and impacts create a link with the policy systems that organise societies, as science – or more precisely the technology emerging from it – becomes (part of) the cause of major policy questions. Nuclear power technology for instance is a product of science. Beyond producing electricity, it produces radioactive wastes as well as very specific societal risks (e.g. proliferation, accidents, malevolence) which have become major policy issues.

The second intersection results from the fact that the environment – again both natural and societal – impacts on science, either directly, for instance the physical environment constrains the options of science, or indirectly as this impact can be mediated via a politicisation of issues. The issue of anthropogenic climate change is illustrative here as both climatic events and the way climate change is taken up as an important political issue impact on the way climate science is conducted and on the kind of results emerging from it.

2.4 Intersection between Science and Policy

I have attempted to clarify the nature of the intersection between the scientific system and the policy system. Table 1 summarises the domains composing this intersection, which are located at different levels and relate to different aspects of science.

Many of these intersecting domains stem from the constant intermingling between facts and values, in both the scientific and the policy processes.[3] We shall see in the next section that this is a recurrent theme, underlying many of the theoretical problems that arise at the intersection between science and policy. Furthermore, the nature of the domains of intersection presented leads to a representation of science and policy as not only intersecting, but also co-evolving domains of human activities.

Table 1: Intersection between Science and Policy

Aspects of science	Domains of intersection between science and policy
Outputs	Articulation of objective and subjective knowledge. Scientific knowledge as an ingredient of policy-making (explanations, predictions). Science contributes to emergence of issues on political agenda.
Processes	
Defining, framing, addressing a problem, designing potential solutions	Pertain to both the scientific and the policy process.
Organisation and funding of research	Science policy is driven by political considerations. Results of science influence policy prioritisation.
Quality and validation processes	Scientific validation process belongs to both science and policy processes.
Education and training processes	Policy influence on orientation of education and training. Influence of education and training on role of science in policy.
Networking processes	Vehicle to channel scientific input to policy.
Actors	Scientific experts in policy processes. Scientific actors influencing policy according to their values and interests.
Context	Technology becomes cause of major policy issues. Politicisation of issues impact on the way science is conducted.

[3] For a discussion on linking science and policy while going beyond the distinction between fact and values see [32].

3 Science-policy interfaces: addressing the theoretical problems arising at the intersection between science and policy

The intersection between science and policy described in the previous section raises a series of theoretical questions (most of which of epistemological nature) which I shall now explore. To address ('manage') the intersection between science and policy and the problems it poses, some processes are implemented – spontaneously or not – which happen precisely at the intersection and which I call 'science-policy interfaces'. These can be defined as social processes which encompass relations between scientists and other actors in the policy process, and which allow for exchanges, co-evolution, and joint construction of knowledge with the aim of enriching decision-making.

Going again through the outputs, processes, actors and context of the scientific system, we can identify the theoretical problems emerging at the intersection and see how, from these, one can derive a series of normative requirements for the interfaces, which are summarised in table 2 at the end of section 3.

3.1 Outputs of Science

3.1.1 Complex world, science, uncertainty, and plurality

The first theoretical problem associated with scientific outputs relates to the meaning of scientific input to policy-making under conditions of complexity and uncertainty. Many societal and environmental issues concern complex, non-equilibrium and self-organising systems characterised by properties of emergence, irreducible uncertainties, non-linear internal causality and indeterminacy. Nonetheless, many "official" scientific discourses around policy issues are framed in terms of certainty. This is illustrated for instance by debates over nuclear waste management and nuclear power generation where solutions are presented as sound and safe (and by the way also value-free), while the areas of uncertainty, indeterminacy and ignorance are not addressed publicly, as if it would weaken the credibility of science and of scientists (see e.g., [16]). This situation is all the more surprising since it is amply recognised (at least in scientific circles) that all scientific knowledge is by nature uncertain and that scientific proof is always provisional.[4] This contradiction is documented in the field of policy-relevant science by Harremoës et al. ([21], p.185) who see it as a *"dual identity for science"* and *"the cause of considerable tensions, not least because the contradiction between intrinsic provisionality and pretended certainty often goes unacknowledged (…)."* Seen from the point of view of discursive democracy[5], this certainty stance is counterproductive, as "certainty discourses" from science might erode trust. Today there is increasing public distrust in science and technology, which built up as a result of a series of significant failures to deal with environmental and health risks (e.g. the cases of BSE, asbestos, ozone layer destruction and many more[6]).

Hence the question we are confronted with is: what sort of knowledge can science bring into decision processes involving complex issues? An important aspect of complexity is the indeterminacy which is unavoidably associated to it. Complexity corresponds to situations for which it is not possible to precisely know the initial conditions of the system. This means that it is not possible to predict the evolution of the system even though it could be subject to deterministic equations. This is the case for instance of strange attractors in chaos theory which present a very high sensitivity to initial conditions: very close initial conditions can lead to radically different evolutions of the system. [34, 35, 36].[7] The study of complexity takes us

[4] One can never know with certainty whether a theory is true, while one may (sometimes) know with reasonable certainty that a theory is false. [24]

[5] On discursive democracy see e.g., Dryzek [33].

[6] See e.g. Harremoës et al. [22].

[7] Contrary to a 'complicated' system, a 'complex' system is characterised by the fact that, in a region of the phase space as small as one wants, one will find neighbouring points representing states which will give radically

away not only from the idea of predictability but also from the ('ideal' of) determinism which has underlain most western science for centuries. Physicists are now looking at highly unstable systems, such as for instance some non-integrable dynamic systems [37]. They show that for such systems determinism is no longer an option, even if one could know the initial conditions with an infinite precision. For these non-integrable systems the very notion of trajectory in the phase space looses its relevance and the only possible description is in terms of probabilities.[8] Note that this is not the result of our limited capacities of observation or computation, it is a consequence of the non-integrability of the problem. *"[Instability] destroys the equivalence between the individual and the statistical levels so that probabilities take an intrinsic signification that is irreducible to an interpretation in terms of ignorance and approximation."* (ibid., p. 39, my translation) In this way, indeterminacy appears at the very heart of our understanding of natural –and *a fortiori* of human– systems. As a consequence, there will always remain an irreducible uncertainty in our predictions concerning the future evolution of complex natural and social systems –including in particular the evolution of socioeconomic systems in their inter-relation with ecological systems. Based on science studies analysis of the process of scientific knowledge creation, Wynne [38] also stresses another type of indeterminacy: a form of subjective and contingent indeterminacy which underlies the very construction of scientific knowledge.[9] This indeterminacy stems from the fact that scientific knowledge is conditional in the sense that it artificially freezes "a surrounding context which may or may not be this way in real-life situations" (ibid. 116), the latter question being indeterminate and open-ended. The unavoidability of indeterminacy and ambiguity is important to our discussion because it questions the very idea that science can make deterministic predictions to drive policy.

Finally, when reflecting on scientific knowledge for decision-making one needs to recall that ignorance is an unavoidable part of science, as sometimes we do not even know what we do not know. ([39], pp. 45s) So the science that is involved in science-policy interfaces has to deal with –and live with– uncertainty, indeterminacy, ambiguity and ignorance. And although some of the uncertainties at hand are reducible through more research, others are inherent to the systems under consideration and/or the scientific process and are here to stay. Another important consequence of this is that we are unavoidably confronted with an irreducible plurality of valid standpoints [40, 41] and of (objectively and subjectively) valid descriptions of the world, both within the realm of science –hence there exists no unique explanation nor prediction but a plurality of scientific viewpoints– and in general –hence the existence of a plurality of representations of the world. The bottom-line is that there exists no unique explanation of the world that could motivate or justify policy.

The existence of irreducible uncertainties and indeterminacy points to a first normative requirement for science-policy interfaces: they need to bring about communication and debate about assumptions, choices and uncertainties, and about the limits of scientific knowledge.[10] In other words, scientific knowledge pertaining to the science-policy interface should systematically include reflective information on boundaries, uncertainties, indeterminacy, and ambiguity, as well as acknowledgement of ignorance and of the irreducible plurality of valid standpoints. Contrary to some *a priori* fears of relativism that are often found in both scientific and policy communities, such transparency and explicit statement of boundaries does not weaken the power of science – or maybe only some undue power – but can correspond to a reinforcement of scientific quality. As regards ignorance –

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different trajectories for the evolution of the system. We are in a situation where there is no independence between the law of evolution of the system and its initial conditions. (see [34], p. 324)

[8] This comes from the existence of resonances between the degrees of liberty of the system: at the points in the phase space corresponding to these resonances, calculating trajectories becomes mathematically impossible ([37], pp. 45-46)

[9] To distinguish it from the physical indeterminacy, Stirling [39] proposes to use the term 'ambiguity', which I will do in the following pages.

[10] van der Sluijs [42] uses a monster metaphor to explore strategies for coping with uncertainty at the science-policy interface.

the unknown unknown – Wynne ([38], p. 115) stresses that the problem rather arises when it is concealed: *"Ignorance is endemic to scientific knowledge, which has to reduce the framework of the known to what is amenable to its own parochial methods and models. This only becomes a problem when (as is usual) scientific knowledge is misunderstood and is institutionalised in policy making as if this condition did not pervade all competent scientific knowledge."* While acknowledging the plurality of valid standpoints does by no means entail falling into *"the chaos of epistemological relativism"* as *"even where the truth is plural, it is still possible to be just plain wrong"*. Stirling ([39], p. 41) Moreover, this acknowledgement leads to the recognition that scientific knowledge is not the only type of knowledge relevant to a science-policy interface: other types of knowledge –local-, indigenous-, political-, moral- and institutional knowledges – are also exchanged and created. To quote Wynne again: *"This institutionalised exaggeration of the scope and power of scientific knowledge creates a vacuum in which should exist a vital social discourse about the conditions and boundaries of scientific knowledge in relation to social and moral knowledge."* ([38], p. 115) From a normative point of view, the consequence is that science-policy interfaces must allow for the articulation of these different types of knowledge. As for the existence of a plurality of standpoint, not only should they be acknowledged and made explicit, but there needs to be room for a transparent negotiation among standpoints in the link with policy processes. One potential way of creating such room is to ensure that science-policy interfaces are participatory, as participatory settings allow for the various and often irreconcilable values underlying problem definition and social choices to be explicitly introduced and accounted for in the scientific quality process [40, 43] and in the wider societal debate [19, 41]

3.1.2 Science for science and science for action

The next theoretical problem has to do with to the role of science and of scientists. We have seen in the first section that science can be *curiosity-driven* science of the kind that is driven mainly by our curiosity to understand and explain the world around us and ourselves or it can be *issue-driven*, if its primary objective is to solve a societal problem[11] [1] – that is, science oriented towards action.

Ironically today two antinomic factors are combining to drive science increasingly towards issue-driven approaches and away from curiosity-driven research. On the one hand, the acute nature of the environmental crisis gives a sense of urgency to the development of knowledge on which to ground action. Lubchenco [44] for instance stresses that, in a rapidly changing world where complex environmental issues are becoming ever more pressing, the role of science cannot be confined to its "traditional" roles of discovering (that is, explaining), communicating and applying knowledge (that is, supporting action), and training the next generation of scientists. Scientists are called upon to address the most urgent needs of society. While the technological spin-offs of science themselves pose critical societal and environmental risks, the appraisal (and management) of which necessitates inputs from scientists. [21] On the other hand the current dominant ideological focus on growth and competitiveness needs 'useful' science and marketable technologies. This is exemplified for instance by the European Framework Programmes for Research, as mentioned in section 2.2.

Although the distinction between issue-driven and curiosity-driven science is useful to address the motives of science, these categories should be understood as ideal-types and, in practice, there is no "pure-type" of one or the other. A more precise representation is that of a process that combines the two kinds of research which build on each other. A paleo-oceanographer for instance may be driven by his curiosity when trying to understand the influence of southern oceanic currents on past climate changes, but his curiosity might have been triggered – or the way he is framing his questions might be oriented – by the existence of an anthropogenic climate change issue. The point is that in real life, curiosity-driven and

[11] When I talk about societal problems or issues, it includes environmental issues, since for the latter society and the environment cannot be disentangled.

issue-driven sciences go hand in hand and that there might be a danger in wanting to isolate one from the other. The former might lead to the discovery of an unsuspected societal issue, to the development of a technology which will turn out to create a societal issue, or to the unexpected discovery of an innovative solution to a problem that was not at the origin of the investigation. The later might trigger curiosity in new areas of investigation. But the emphasis of science can indeed be shifted more towards one or the other ideals and the intersection between science and policy undervalorises curiosity-driven science even though it has an important role to play. The duality of scientific motives creates a first normative requirement for the science-policy interfaces which need to allow for balancing the relative importance of outputs from issue-driven and curiosity-driven science and for their articulation into policy-relevant knowledge. This in turns implies that the interface between science and 'science policy' –the policy domain dealing with science prioritisation and funding– is an extremely important component of any science-policy interface [13].

3.1.3 When prediction is not enough

In the first section, we have seen that science aims at providing explanations and predictions. Our next theoretical problem relates to the question: "Which of these two types of outputs of science are we talking about when scientific knowledge is to be used to orient action?" Both Poincarré and Thom stressed the importance of prediction for action. But predictions are not enough, indeed both explanations and predictions come to bear in deciding upon how to act: explanations because when we make a decision we build on a certain understanding of the world, and predictions because when making a decision we have certain anticipations or expectations on the future evolution of the world.

Prediction is part of the method of science, since a key characteristic of scientific knowledge is the possibility to falsify a scientific theory. As stressed by Karl Popper: "the criterion of scientific of a theory resides in the possibility of invalidating it, refuting it or else testing it." ([24], p. 65, my translation). Experimental test of a theory involves an experiment that predicts different observable outcomes whether the theory holds or not. [24, 26] But the predictions that are available from science for policy on complex environmental problems are not that straightforward, as they concern the future evolution of complex environmental and/or social systems. Hence the anticipations and expectations which come to bear on policy decisions are not often predictions to which probabilities of occurrence can be unequivocally attached. They are rather much looser predictions and take the form of scenarios, narratives [45, 46], or even merely hopes. In the climate change issue for instance, what scientists can offer to policy are scenarios of plausible evolution of the system under different (and always incomplete) sets of conditions.[12]

Notwithstanding the obvious impossibility of predicting the future, the myth of science providing predictions, based on which policy-makers can mechanistically apply some sort of optimising calculation and come to the 'optimum' or 'best' decision is still pervasive in both science and policy circles. Even if this myth often builds on the best possible intentions, it is both a misleading and damaging vision of both science and policy. We should cautiously reflect on what kind of predictions are made and used in support of action. This discussion suggests a (re-)emphasis of the role of scientific explanations in policy processes. If science cannot provide 'perfect' predictions on which to make a decision, it can nevertheless contribute to a better understanding of the issues at hand, which will in turn support a richer exploration of future scenarios, narratives and policy options, as well as a more articulated justification of decisions.

The emerging normative requirement for science-policy interfaces here is that they should be processes in which scientific knowledge is brought to bear – together with other types of knowledges as we have seen above – to construct a better understanding of the issue at

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[12] See e.g. the key role of the emissions scenarios of the Intergovernmental Panel on Climate Change [47] in both climate science and climate policy.

hand and of possible options for action, as well as better articulated justifications. In particular, if scientific input increases understanding of a policy issue while only allowing highly uncertain projections into the future (if any) one can envisage that other elements than mere prediction be articulated to this understanding and come to bear on the final decisions, such as e.g., ethical values. For instance, one could argue that independently of the future scenarios of climate change, scientific understanding of anthropogenic climate forcing coupled with ethical values for precautionary avoidance of major disruption to key mechanisms of the biosphere are sufficient to justify a pro-active climate policy.

3.2 Processes of Science

3.2.1 The fuzzy frontiers of science

The question of the boundaries of science not only creates a domain of intersection between science and policy but also poses theoretical problems. We have seen in the first section that some processes of (issue-driven) science – such as problem definition and framing, choices of boundaries, variables, parameters, scales and methods – are not isolated from social processes. Hence, beyond the myth of a science confined in clearly defined boundaries which would be univocally and neutrally defined by methods, science is a value-laden social process whose frontiers are fuzzy.[13] So the definition of what is "scientific" is not as unproblematic as might appear at first sight. [14] In the words of Brian Wynne: *"Normative responsibilities and commitments are concealed in the 'natural' discourse of the science, indicating the* fundamentally *negotiable definition of the boundary between science and policy."* ([38] p.125, *emphasis his*)

It is primarily owing to these moving and negotiable boundaries of science that the processes for managing the intersection between science and policy need to be understood as social processes where knowledge co-evolves, is exchanged, and is jointly constructed. Once recognised that independence from society is not defining the frontiers of science, a normative requirement for science-policy interfaces is that they allow for an explicit recognition of, and transparency about, the existing dependencies between the scientific and the social systems and how they come to bear on the knowledge that is exchanged in the interface.

Another consequence here is that science-policy interfaces themselves should not be understood as processes with clearly defined limits which would isolate them from both science and policy. In those interfaces, the different types of relevant knowledges are in constant evolution and co-evolution and they need to be continually and dynamically exchanged across the fuzzy frontiers of science and society. Moreover, there is often no one-to-one relationship between a policy issue and a scientific problem. From these considerations, stems the normative requirement for science-policy interfaces to be dynamic. [13]

Other normative requirements for the science-policy interfaces emerge quite obviously from the domains of intersection created by other procedural dimensions of science examined in the first section (see Table 1). They point to some particular roles for the science-policy interfaces. Specifically, science-policy interfaces should be organised in a way that includes a reflection on research priorities and research organisation. Moreover, they should contribute to the scientific validation process by allowing critical assessment of scientific

[13] Note that the recognition of the fuzzy frontiers of science is not equivalent to abandoning the ideals of neutrality and independence which are constitutive of science. Rather it is an appreciation that these two ideals are just that: ideals which will never be fully reached. Neither does this recognition lead us to abandon objectivity altogether as it does not undermine the possibility of objective knowledge in the Popperian sense. Some knowledge can still be pinned down as (scientifically) non-objective while other can claim scientific objectivity.

[14] See for instance the model suggested by Latour [32] to go beyond the fuzzy dichotomies nature/society and objects/subjects, by broadening the concept of social actors to include associations of both humans and non-humans and creating the "collectif" which brings them together.

outputs in light of users needs and other knowledges. Such assessments should complement and enrich the traditional scientific quality process based on peer review and contribute to the extension of the peer community called for by Funtowicz & Ravetz [1]. The interfaces, as processes located at the intersection between science and policy, should become places where some education and training of scientists takes place, in particular as regards acquisition and development of skills in communication, translation and mediation [48]. Lastly, the interfaces should engage in a transparent manner with existing scientific networks. Note that some of these networks are themselves forms of science-policy interfaces.

3.2.2 The specific roles of social sciences

Another epistemological question stemming from the recognition that science is an inherently social process concerns the specific inputs and roles of social sciences in interfaces between science and policy for environmental issues. Social sciences have a long and pluralistic tradition of studying human aspects of the world: behaviours, activities, societies, and their institutions (political, economic, cultural or social). The question at hand is why and where are they so important for science-policy interfaces? Social sciences have multiple roles to play as I shall now examine.

The first and maybe most obvious of these roles is to contribute to the understanding of the issue at hand by providing explanations for social phenomena and, in the case of environmental issues, how they relate to the natural phenomena in question. Social sciences for these issues are particularly important as the main causes of the global environmental crisis are anthropogenic. For instance, when addressing the biodiversity loss issue, social sciences can contribute to understanding what the anthropogenic drivers of biodiversity change are or what the societal impacts of response strategies would be. Social sciences can also contribute in the prediction exercises that are operating at the science-policy interface, through integrated models, scenarios or narratives for instance.

But social sciences also have other roles to play which relate to the fact that the processes at hand in science, in policy and in science-policy interfaces, are themselves objects of study for the social scientist. This has several important implications. First, social sciences are particularly well placed to make explicit the blurred distinction between facts and values [32] and *"the intimate inter-relationship between values and science"* ([39], p.62). By an interdisciplinary reflection on complex systems, they can highlight the need for pluralistic epistemologies to address complex environmental issues. Kay et al. [45] for instance suggest that new epistemological mindsets must be brought to bear for understanding complex, non-equilibrium and self-organising systems. Giampietro ([49], p.148) proposes *"an epistemology which acknowledges that the observer/narrator is a part of the self-modifying system"*. Stirling [39] shows how insights from environmental social sciences suggest a pluralistic realism to address risks, uncertainty and precaution. And O'Connor [40] builds a social sciences epistemology of reciprocity based on inter-subjectivity, methodological pluralism, rigour as critique, irony as rigour and the dialogical character of social knowledge and social life. Second, social sciences can study and propose procedures for practical implementation of science-policy interfaces, for instance by stressing participatory or interdisciplinary requirements. [13] And social scientists can help implement and assess science-policy interface processes in real life: they can play a direct role as mediators, organisers, facilitators of interfaces. But they are also sometimes particularly well placed to build bridges between the different actors (scientists, policy-makers, other stakeholders) or even between different scientific disciplines.

Overall, we see that beyond their contribution to the development of knowledge on environmental issues and potential solutions, social sciences also have a role to play in the design, implementation and assessment of science-policy interfaces. From this stems the normative requirements that science-policy interfaces should on the one hand allow for genuine interdisciplinary interactions between social and natural sciences, and on the other hand recognise and, when appropriate, exploit the potential of social scientists as designers, implementers and evaluators of science-policy interface processes in real life, as well as their potential role as translators, mediators or facilitators.

3.3 Actors of science

The main theoretical problem raised by the intersection between science and policy at the actor's level is the non-neutrality of scientists. We have seen above that science is a value-laden social process whose frontiers are fuzzy. Scientists themselves are not "neutral": they have their values, their culture, their beliefs, and their interests. And they cannot isolate their scientific work from their values and their multiple roles in society beyond that of scientists – e.g., citizens, consumers, parents, climbers. This is the case not only for private sector funded scientists but for all scientists. Take the case for instance of a scientist who invests a lot of energy and dedication to understand and develop a solution to an environmental problem – say the disposal of long-lived radioactive waste – because of her personal dedication to the issue and the co-development of her own values, she will find it hard to accept that her solution is contested or not chosen. [16] Another example is biodiversity science, where many scientists admit that one of their aims while doing science is to help stop biodiversity loss. This is a value stance that directly informs their activities as scientists. [13]

The issue here is that when scientists get involved in the science-policy interface they enter the process as "complete" personalities, that is: they don't leave their values, beliefs and interests at the door to speak the "truth" in the name of Science. [50] This is against many positivist representations of the activity of expertise as a process of communication of 'objective' and 'neutral' scientific results to policy-makers who will be able to univocally use these results to base their decisions. A danger associated with such representations of the role of science and scientists in policy is that they may lead to manipulation, as illustrated for instance by the all too frequent use by US President George W. Bush and his administration of the terms "sound science", a linguistic trick which turns out to be *"a means of justifying predetermined political conclusions"* [51] or as a means of *"requiring a high burden of proof before taking government action to protect public health and the environment"*[52]. Typically discourses of neutrality and independence (of science or scientists) hide the powerful dominance of actors with particular interests who instrumentalise science to deny any need for debate and negotiation since there is one and only one 'truth'. The greatest danger of such positivist representations, as stressed by Habermas in his critique of the technocratic model, is that the domination of science over politics leads to the disappearance of political decisions which become fictive, and overall of any form of democracy. [29]

Hence scientists are not neutral and they cannot be stripped from their values and interests. The normative requirement stemming from this situation is that science-policy interfaces should render explicit the values, ethics and interests of knowledge holders and allow for their articulation with (objective and subjective) knowledge.

3.4 Context of science

We have seen in the previous section that, at the context level, a series of intersections between science and policy come from the fact that science is an open system that is not isolated from society and the environment. These intersections stem in particular from the societal and environmental impacts of technological development, from the role of science in agenda setting, and from the impact of political uptake of some issues on the conduct of science. The theoretical question arising here is that of the responsibility of science and scientists as knowledge holders and technology developers. Confronted with pressing societal and environmental issues and risks, some of which are a direct consequence of technological developments resulting from science, scientists – wherever they are located on the continuum between issue-driven and curiosity-driven research – have a responsibility to be more reflexive about the consequences of science and technology, as was recognised by

Jürgen Habermas already in 1963: *"To the extent that the sciences are really taken into the service of political practice, scientists are objectively compelled to go beyond the technical recommendations that they produce and reflect upon their practical consequences."* ([29], p.78) More generally, the role and responsibilities of scientists need to be enlarged to include participation to the science-policy interface processes. And the interface processes must be such that they allow scientists to exercise their responsibility.

Table 2: Theoretical problems at the Science-Policy intersection and normative requirements for the interfaces

Theoretical problems	Normative requirements / Challenges for science-policy interfaces
Outputs	
Complexity, uncertainty, indeterminacy	To bring about communication and debate about assumptions, choices and uncertainties, and about the limits of scientific knowledge. To allow for articulation of different types of knowledge: scientific-, local-, indigenous-, political-, moral-, and institutional knowledges. To provide room for a transparent negotiation among standpoints (participatory processes).
Issue-driven vs. curiosity-driven science	To allow for balancing issue-driven and curiosity-driven science and their articulation in knowledge for decision-making processes.
Roles of scientific explanations and predictions	To allow for a reemphasis of the role of scientific explanation for understanding the issue, exploring options for action, and building justifications.
Processes	
Fuzzy frontiers between science and policy	To allow for recognition of the existing dependencies between the scientific and the social systems and how they influence the knowledge that is exchanged in the interface. To allow for continuous creation and dynamic exchange of different knowledges across the frontiers of science and society (dynamic processes).
Prioritising and organising research	To include a reflection on research priorities and research organisation.
Scientific quality	To allow for critical assessment of scientific outputs in light of users needs and other knowledges.
Educating scientists	To allow for education and training of scientists in communication, translation and mediation.
Role of scientific networks	To engage in a transparent manner with existing scientific networks.
Inputs and roles of social sciences in science-policy interfaces	To allow for genuine interdisciplinary interactions between social and natural sciences. To recognise the potential of social scientists as designers, implementers and evaluators of science-policy interfaces, and their potential role as translators, mediators or facilitators.
Actors	
Non-neutrality of scientists and possibility of objective knowledge	To render explicit the values, ethics and interests of knowledge holders and allow for their articulation with (objective and subjective) knowledge.
Context	
Responsibility of knowledge holders and technology developers (scientists)	To allow for scientists to exercise their responsibility.

4 Conclusion

In recent years there has been a growing activity around the topic of science-policy interfaces, primarily in terms of practices and discourses, and to a lesser extent in terms of research. Science-policy interfaces seem to have become both a fashionable and an unavoidable topic. A key reason behind the emergence of this concept is that it captures a series of practical experiences and needs, and reflects theoretical and methodological interrogations.

In this paper, I have attempted a theoretical exploration of science-policy interface, in the particular context of environmental governance. I started by searching for domains of intersections between science and policy to show that science and policy, far from being mutually exclusive and hermetic categories are intersecting domains of human activities which are in co-evolution. The three questions that have been guiding the argument could then be answered, even if only provisionally. To the question of what science-policy interfaces are, the proposed answer is that they are social processes which encompass relations between scientists and other actors in the policy process, and which allow for exchanges, co-evolution, and joint construction of knowledge with the aim of enriching decision-making. To the question of the rationale for the existence of such interfaces, the suggestion is that they are processes that are implemented to manage the intersection between science and policy. To the question of how they should operate, the answer offered lies in a set of normative requirements and challenges for science-policy interfaces (table 2). Such normative content emerged from the theoretical problems which were identified at the domains of intersection between science and policy and is justified by these problems.

In practice the design, implementation and/or assessment of science-policy interfaces remains a challenge and there is a definite need for innovative designs, case studies and benchmarking of existing interfaces. The normative requirements identified here may serve as a guiding tool when designing, implementing, or evaluating real-life science-policy interfaces. A series of methodological issues will also need to be considered. They require further theoretical investigation, practical experimentation and critical debates.[15] These include questions pertaining to: (i) the reinforcement and enlargement of scientific quality and validation processes; (ii) the development of transdisciplinary research methodologies [53]; (iii) transparency, participation and dynamism of interfaces, in particular the role of other stakeholders and the public; (iv) accountability of the different actors; (v) translation of scientific knowledge into policy-relevant knowledge and of policy knowledge into science-relevant knowledge; (vi) the inclusion of a diversity of knowledges and intelligences; (vii) the development of dialogical dissemination channels for scientific knowledge which specifically target the various potential user groups; and (viii) the institutionalisation of science-policy interfaces in a democratic context.

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[15] We have started to address some of these issues in [13] and [14].

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