**Anthropocene, planetary boundaries and tipping points: interdisciplinarity and values in Earth system science**

*Accepted in European Journal for Philosophy of Science*

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18 March 2024

Abstract

Earth system science (ESS) and modelling have given rise to a new conceptual framework in the recent decades, which goes much beyond climate science. Indeed, Earth system science and modelling have the ambition "to build a unified understanding of the Earth", involving not only the physical Earth system components (atmosphere, cryosphere, land, ocean, lithosphere) but also all the relevant human and social processes interacting with them. This unified understanding that ESS aims to achieve raises a number of epistemological issues about interdisciplinarity. We argue that the interdisciplinary relations in ESS between natural and social / human sciences are best characterized in terms of what is called 'scientific imperialism' in the literature and we show that this imperialistic feature has some detrimental epistemic and non-epistemic effects, notably when addressing the issue of values in ESS. This paper considers in particular the core ESS concepts of Anthropocene, planetary boundaries and tipping points in the light of the philosophy of science discussions on interdisciplinarity and values. We show that acknowledging the interconnections between interdisciplinarity and values suggests ways for ESS to move forward in view of addressing the climate and environmental challenges.

## 1. Introduction

In many ways, Earth system science (ESS) and modelling have given rise to a new conceptual framework in the recent decades, which goes much beyond climate science. Indeed, Earth system science and modelling have the ambition "to build a unified understanding of the Earth", which involves not only the "interacting physical, chemical, and biological processes between the atmosphere, cryosphere, land, ocean, and lithosphere" (Steffen et al. 2020, 54)—a daunting task in itself—but also all the relevant human and social processes interacting with these Earth system components. Recent developments in Earth system modelling make this last point very explicit: for instance, Donges et al. (2021) introduce the term "World-Earth system" in order to highlight that "human societies, their cultures, knowledge and artefacts (the "World") should now be included on equal terms in a new family of models" (1116). "World-Earth system" aims to contrast with "Earth system", for instance as it is commonly used in climate modelling. Indeed, Earth system models—e.g. within the context of the reports of the Intergovernmental Panel on Climate Change (IPCC)—tend to be focused mainly on the dynamics of the physical components of the Earth system, with only limited consideration for the social dynamics of the human societies—something that can be considered somewhat paradoxical in a field (ESS) that aims provide a conceptual framework for understanding the planetary-scale impacts of human activities (see Lövbrand et al. 2015, §2.2).

The unified understanding that ESS aims to achieve should involves many different disciplines both from the natural and social sciences, and fundamentally requires some level of interdisciplinarity in the broad sense of "integrating information, data, techniques, tools, perspectives, concepts, and/or theories" (National Academy of Sciences 2005, 2) from different disciplines and interactions among them. This need for interdisciplinarity is explicitly acknowledged by Earth system scientists; for instance, in the first paragraph of an introductory textbook on the topic, Tim Lenton writes that "Earth system science is thus a deeply interdisciplinary field" (2016, 1) and similarly, Steffen et al. (2020, 56) note that in the early days of Earth system science (i.e. 1980s), "[r]eports, workshops and conferences all agreed that ESS, given the very nature of its object, should be interdisciplinary".

Now, the very notion of interdisciplinarity and how exactly the interdisciplinary interactions should concretely be implemented in a given context raise many epistemological and methodological questions, and there is indeed a substantial philosophy of science literature on interdisciplinarity.[1] However, there is little philosophical discussion of interdisciplinary interactions in Earth system science and modelling, despite the fundamental epistemological and methodological issues that arise in this context between the natural sciences on the one hand, and the social and human sciences on the

[1] For instance, see Hirsch Hadorn et al. (2008), Frodeman et al. (2010), Hoffman et al. (2013), Frodeman (2014), Mäki (2016), MacLeod and Nagatsu (2018).

other. In this paper, we consider the conceptual framework of Earth system science in the light of recent philosophy of science work on interdisciplinarity and values in science, highlighting the interconnections between the two. In particular, the paper puts current critical social science discussions of core ESS concepts (Anthropocene, planetary boundaries and tipping points) in an epistemological perspective about interdisciplinarity. The aim is to provide a better understanding of the ESS framework, its strengths and limitations, in view of addressing the climate and environmental challenges.

Section 2 introduces the global ESS articulation of the influential concepts of Anthropocene, planetary boundaries and tipping points. These concepts have been subject to a social science critique, which we relate to the way interdisciplinarity is implemented in ESS. Indeed, we argue that the interdisciplinary relations in ESS between natural and social / human sciences are best characterized in terms of what is called 'scientific imperialism' in the literature on interdisciplinarity (section 3). We will see that this imperialistic nature of interdisciplinarity in ESS has some detrimental epistemic and non-epistemic effects, notably when addressing the issue of values in ESS (section 4). Seriously acknowledging the interconnections between interdisciplinarity and values suggests ways for ESS to move forward in the face of the climate and environmental challenges (section 5).

## 2. Three core concepts of Earth system science and a common critique

Three interrelated concepts are especially representative of the global conceptual framework of ESS (see Steffen et al. 2020, 59-62). First, the concept of Anthropocene aims to denote a new geological epoch characterized by the planetary-scale impact of human activities, putting the Earth system on a trajectory away from the conditions of the Holocene. Second, the concept of planetary boundaries aims to identify a "safe operating space for humanity" in terms of "boundaries for anthropogenic perturbation of critical Earth-system processes" (Steffen et al. 2015). Third, the concept of climate tipping points "refers to a critical threshold at which a tiny perturbation can qualitatively alter the state or the development of a system" (Lenton et al. 2008, 1786), such as the climate system or other subsystems of the Earth system.[2] The more formal definitions of tipping points in ESS exploit the mathematical framework of dynamical systems theory, and require that the parameters characterizing the system can be combined in single control parameter (or a small number of control parameters), whose critical values corresponds to tipping points (Lenton et al. 2008).

[2] In a recent paper on the topic, Armstrong McKay et al. (2022) adopt the following more specific definition, explicitly highlighting some of the features of climate tipping points: "Tipping points occur when change in part of the climate system becomes (i) self-perpetuating beyond (ii) a warming threshold as a result of asymmetry in the relevant feedbacks, leading to (iii) substantial and widespread Earth system impacts."

The concepts of Anthropocene, planetary boundaries and tipping points encode the global perspective of ESS in the sense that they can be understood in terms of trajectories or features of the Earth system as a whole. In many ways, this global nature is closely related to a common critique that these concepts have been subject to, mainly in the social science literature: one of the main worries is that this global conceptual framework tends to promote a homogenising perspective that is blind to the various different historical, socio-political and ethical aspects that are connected to these concepts and that are key to understand the (diversity of) climate and environmental challenges.[3] According to this critique, the Earth system narrative of the Anthropocene tends to contract "the social diversity and difference into a single path for humanity", which can lead to losing "sight of the situated conflicts, warped distribution of wealth and unequal power relations that engine the 'great acceleration' characterizing this new epoch" (Lövbrand et al. 2015, 213-214). Concerning the concept of planetary boundaries, Biermann and Kim (2020) similarly stress that it "was not designed to account for the regional distribution of causes and consequences of earth system transformations, historical patterns, or societal issues broadly defined" (502), so that the related discourse is "seen in the South as unfair given past colonialism and current Northern overconsumption" (514). The concept of a planetary threshold generated by a cascade of interacting climate tipping points, which are understood in terms of a relatively small number of control parameters, naturally invites what Lövbrand et al. (2015, 217) call "techno-managerial planning and expert administration"—often expressed in terms of Earth system stewardship in the ESS literature, as in Steffen et al. (2018)—and the worry is that this global and top-down stance might come "at the expense of democratic debate and contestation" (Lövbrand et al. 2015, 217).

In the last decade, there has been a substantial literature in social science discussing these concepts—in particular the Anthropocene and planetary boundaries concepts—and the comments above are not meant to do justice to the richness of these works. What we want to highlight is that a broad common critique can be identified in these social science analyses: the concepts of Anthropocene, planetary boundaries and tipping points, as articulated within the global ESS framework, can have homogenising and depoliticizing effects with undesired (e.g. undemocratic, unfair, counterproductive) consequences in view of addressing in a just way the climate and environmental challenges.

This critique is all the more relevant given the fact that these concepts play a central role in the (political) narrative that aims to highlight the threats posed by climate change and/or to show a certain

[3] To a certain extent, these homogenisation effects already occur in the context of climate (change) science, where a fundamental tension between the global and local levels has been argued to lie at the heart of the difficulties to address the climate challenge (see, e.g., Shepherd and Sobel 2020). We are grateful to an anonymous referee for highlighting this point to us.

level of commitment to the issue. For instance, António Guterres, the Secretary-General of the United Nations (UN), has on several occasions referred to the threat of climate tipping points in high-profile speeches, such as in the opening of the 2022 UN Climate Change Conference (COP27), where he warned that "our planet is fast approaching tipping points that will make climate chaos irreversible". Similarly, concerns about climate tipping points and planetary boundaries underlie the notion of climate emergency,[4] which has been officially acknowledged by an increasing number of governments around the world. In this emergency context, the worry is that the concepts of tipping points and planetary boundaries (with the Anthropocene in the background) can help justify controversial technologies such as solar radiation management and, more generally, non-democratic forms of environmental governance (Sillmann et al. 2015).

In the next sections, we consider these core ESS concepts and their social science critique in the light of recent philosophical discussions on interdisciplinarity and values, with the aim to suggest a better articulation of these important notions and of the conceptual framework of ESS more generally.

## 3. Earth system science: interdisciplinarity as scientific imperialism

### 3.1 Three aspects of scientific imperialism

Interdisciplinarity as a field of study is extremely broad, and we do not intend (and do not need) to enter the intricate debates around interdisciplinarity. We are here rather interested in a specifically epistemological perspective on interdisciplinarity, and in particular we will exploit the notion of scientific imperialism, which can be broadly understood "as a type of interdisciplinary relation in which one scientific discipline occupies or enters into another discipline's domain" (Mäki et al. 2017). In this broad descriptive sense, scientific imperialism does not necessarily have a negative connotation, as for instance in Durpé (1994):[5] it is first taken as a tool to characterize and understand certain interdisciplinary relations. In a second step, cases of scientific imperialism can then be evaluated in a normative perspective.

ESS is fundamentally an interdisciplinary field, which at its core involves "elements of geology, biology, chemistry, physics and mathematics" (Lenton 2016, 1). Moreover, as we have highlighted in section 1, the field has in recent years developed the ambition to "fully integrate human dynamics, as

[4] For instance, in a highly cited comment in *Nature*, high-profile Earth system scientists write that "the consideration of tipping points helps to define that we are in a climate emergency", which, according to the authors, must "compel political and economic action on emissions" (Lenton et al. 2019, 592); see also the "World Scientists' Warning of a Climate Emergency" (Ripple et al. 2020), which has more than 14'700 signatories, and its updates (Ripple et al. 2021, 2022).

[5] In a normative approach, Dupré (1994) has heavily criticized scientific imperialism, focusing in particular on economics (and evolutionary biology), whose "incursions into various domains" clearly illustrate the fact that "alien intellectual strategies may import inappropriate and even dangerous assumptions into the colonized domains" (380).

embodied in the social sciences and humanities, with biophysical dynamics in a truly unified ESS effort" (Steffen et al. 2020, 61). So, ESS involves a variety of different interdisciplinary relations, among the natural science disciplines themselves, but also between the natural science disciplines on the one hand and the social and human science disciplines on the other hand. We focus on the latter, arguing that this type of interdisciplinary relations within ESS can be understood as a case of scientific imperialism. In the context of ESS, it is really about the specific ('imperialistic') stance of the natural sciences with respect to the domain(s) of the social and human sciences (rather than one specific discipline invading the domain of another specific discipline).

To this aim, we consider three aspects of scientific imperialism as defined by Mäki (2013); these distinct but interrelated aspects will help us to characterize and evaluate the interdisciplinary relations at work within the framework of ESS—in particular those at work between the natural and social science domains as well as those articulated in the core ESS concepts discussed in the previous section.

> "*Imperialism of scope*. An expansionist discipline seeks to explain phenomena that belong to the perceived domain of another discipline. This is the pursuit of explanatory unification that is disrespectful for disciplinary boundaries.
>
> *Imperialism of style*. The styles and strategies of research, such as the techniques and standards of inquiry and communication, characteristic of one discipline, are transferred to, or imposed on, other disciplines.
>
> *Imperialism of standing*. The academic and non-academic prestige, power, and resources as well as the acknowledged technological and political relevance of one discipline increase at the expense of those of another." (Mäki 2013, 334)

### 3.2 Imperialism of scope

Imperialism of scope entails one (set of) discipline(s) encroaching on the usual domain of another (set of) discipline(s), such that the explanations provided by the 'invaded' discipline(s) may be de facto superseded by those of the 'invading' discipline(s). This encroachment is a matter of degree, and indeed ESS clearly involves some level of imperialism of scope, in particular on the domain of the social sciences.[6] For instance, as mentioned above, recent developments in ESS explicitly have the ambition

[6] The social sciences are comprised by variety of different approaches, and so, may not be best characterized as a single discipline, which however does not prevent their domain(s) from being subject to scientific imperialism (as we have mentioned above); in the context of the discussion of scientific imperialism, Mäki indeed notes that disciplines "typically are not fully uniform and unified wholes but rather more or less—in some cases more, in some others less—fragmented and changing structures with various components that are rigid or flexible in different degrees" (2013, 335). We are grateful to an anonymous referee for highlighting this point to us.

to understand (and to a certain extent, to explain) "the dynamics of human societies" (Steffen et al. 2020, 61) as well as their interactions with nature (Donges et al. 2021), which typically constitute central topics in social sciences (as a paradigmatic example, consider the Marxist analyses of the evolution of societies).

According to Mäki (2013), a central ("ontological") constraint for a legitimate imperialism of scope is the pursuit of explanatory and ontological unification, where the former relies on the latter and where ontological unification is broadly understood as the "discovery of the extent to which there is unity in the world itself" (336). Unification understood in this sense is indeed a common objective in the natural sciences, where it has very often a normative (positive) connotation (although not all unification accounts of explanation are ontological). In this perspective, achieving some degree of unification is an important condition for an imperialism of scope to be legitimate and even desirable.[7]

Now, we want to emphasize that unification understood as a normative constraint is debated in philosophy of science. Following Longino (1996), it can be argued that unification may contribute to "ontological homogeneity" by way of giving priority to a privileged class of entities, which are the product of a historically and institutionally determined disciplinary culture, and whose broader legitimacy can be disputed. Beyond the metaphysical aspects, the important point here is that this ontological homogenisation may lead to overlook relevant differences between different types of entities. From this point of view, ontological heterogeneity can be seen as a legitimate value, since "[o]ntological heterogeneity permits equal standing for different types, and mandates investigation of the details of such difference" (Longino 1996, 47). As a consequence, according to Mäki's ontological constraint, whether or not imperialism of scope is seen as legitimate in a given context depends on whether or not unification is seen as legitimate in that context.

In many ways, this unificatory move is at the very heart of the ESS project, since ESS aims to encompass under a single umbrella both the relevant natural and social systems composing the Earth system. This endeavour finds a motivation in the very concept of Anthropocene, where the planetary impact of human activities is often conceived to imply the "end of nature", that is, the irrelevance of the nature/society dichotomy, hence favouring a form of explanatory and ontological homogeneity. As we just mentioned, evaluating the legitimacy of the imperialism of scope at work in ESS is then a

[7] According to Mäki (2013), this ontological constraint is part of a set of four jointly sufficient normative constraints for scientific imperialism to be "acceptable and even desirable" (ontological, epistemological, axiological and institutional constraint). These normative constraints are very much shaped by the paradigmatic example of scientific imperialism considered in the interdisciplinarity literature, namely economics imperialism (Mäki 2009), and do not all apply equally well to the case of ESS. As Mäki himself puts it, scientific imperialism "is a complex and fluid phenomenon with both institutional and epistemic aspects and a variety of types and dimensions—and hard-to-classify boundary cases. This is why no single compact definition can be given and why its empirical identification and normative evaluation tend to be so difficult." (2013, 333-334) In this spirit, we take a rather liberal attitude when applying (some of) these normative constraints.

matter of evaluating the legitimacy of such homogenisation within the framework of ESS. We have seen in section 2 that one of the main critiques from the social sciences precisely concerns various aspects in which such a homogenisation can be problematic when it comes to social systems.

### 3.3 Imperialism of style

Let's now consider the two other aspects of scientific imperialism. Imperialism of style refers to the transfer from one discipline to another of what is sometimes broadly called "epistemic culture" in the social sciences (Knorr Cetina 1999).[8] Within the framework of ESS, the ambition is explicitly to transfer the global research strategy that is characteristic of climate science (e.g. in terms of global numerical models) from the domain of the natural subsystems of the Earth system (such as the atmosphere or the ocean) to the domain of social systems (such as "human societies, their cultures, knowledge and artefacts" as Donges et al. 2021, 1116 put it).

Of course, the use of modelling methods from the natural sciences to understand social systems and their interactions with their environment is widespread. Indeed, various approaches in social sciences make heavy use of computational modelling, such as agent-based modelling, typically involving game-theoretic and complex systems methods.[9] These computational approaches could be seen as involving an imperialism of style to a certain extent—it is a matter of degree—in the sense of a transfer of modelling techniques from the natural sciences to the social sciences—of course, this depends on how 'social sciences' are understood in the first place (and we have already commented above that they may be hard to construe as a homogeneous discipline).

In the context of ESS and its recent developments (e.g. in terms of 'World-Earth system', see section 1), the understanding of social systems and processes (only) through the modelling lens amounts to an imperialism of style from the perspective of the critical and interpretative social science

[8] Epistemic cultures are defined as "cultures of creating and warranting knowledge […] and as amalgams of arrangements of mechanisms and elements bound together by affinity, necessity, and historical coincidence which, in a given field, make up how we know what we know" (Knorr Cetina and Reichmann 2015, 873). This concept is closely connected to the other social science concepts of "epistemic lifestyles" (Shackley 2001) and "epistemic community" (Haas 1992).

[9] Indeed, Kollman (2012, 367) notes that "[t]he literature on computational models in the social sciences has grown vast and has presented many varieties of models. Economists have used computational models to analyze herd behavior in markets, fashion trends, career choice, social choice, strategic price setting, and broad macro-economic patterns, both global and local. Sociologists study sorting, the emergence of social movements, cultural change, and organizational behavior both within and among organizations, and the relationships between group behavior and individual behavior. Within political science, computational models have been applied to the study of international diplomacy and war, electoral competition, voting systems, the evolution of cooperative behavior, criminal behavior and punishment, political networks, and the development of law. Social psychologists have modeled herding, habit formation, and how individual perception interacts with group behavior."

traditions.[10] For instance, 'World-Earth system' modelling within ESS aims to include socio-cultural aspects such as "individual and collective opinions, behaviours, preferences and expectations, and their social network dynamics" as well as "social norms and value systems" (Donges et al. 2021), together with feedback loops between these socio-cultural features and environmental ones. From the critical social science perspective, the exclusive focus on modelling studies in ESS leads to what O'Brian and Barnett (2013, 381) describe as a situation in which there is "little room within Earth system framings for critical research on the social context and unequal consequences of [the global environmental] changes for different places and groups."

Imperialism of style within ESS not only concerns the transfer of (numerical) modelling methods, but also of concepts and mathematical tools. Indeed, the recent and growing interest in social tipping points in ESS constitutes a good example where conceptual, mathematical and modelling methods from the natural sciences are transferred to the study of the dynamics of social systems. The very definition of a social tipping point within ESS—to the extent that it is explicit—is often directly inspired by the definition of a climate tipping point. For example, the following definition of Milkoreit et al. (2018), which is based on a literature review, is very similar to the standard definition of a climate tipping point (see Lenton et al. 2008): "a social tipping point can be defined as a point within [a socio-ecological system] at which a small quantitative change inevitably triggers a non-linear change in the social component of the [socio-ecological system], driven by a self-reinforcing positive feedback mechanisms, that inevitably and often irreversibly lead to a qualitatively different state of the social system." As this definition illustrates, the conceptual framework within which the notion of social tipping point is articulated in ESS is very much inspired by the mathematical theory of dynamical systems theory. This conceptual framework also enables the application of mathematical and modelling techniques that are characteristic of the natural sciences in view of modelling both climate and social tipping points on an equal footing in the unified ESS perspective (see Donges et al. 2020).

This imperialism of style can be normatively evaluated in the light of Mäki's epistemological constraint, which recommends a "great deal of epistemic caution" (2013, 336); according to Rolin (2018, 54), this constraint requires that "imperialists make explicit the uncertainties involved in their attempts to apply concepts and models to topics traditionally studied in other disciplines". The extent to which such epistemic caution is implemented within ESS is best discussed on a case-by-case basis.

[10] In their article on the different ways in which critical social science can engage with the natural (environmental) science narrative on the Anthropocene, Lövbrand et al. (2015, 212) characterize "the multiple theoretical traditions" under the label "critical social science" in terms of a shared "interest in thinking creatively and critically about the causes, rationalities, practices and politics of environmental research and policy-making"; furthermore, "[r]ather than accepting the world as we find it, work in this field prompt scholars to reflect upon the ideas, norms and power relations that make up the world and to imagine it anew". They mention works in political ecology, science and technology studies and postcolonial studies as examples.

In the social tipping point example, it is acknowledged in the ESS literature that in general social tipping processes display "greater complexity" and are "less predictable" than climate tipping points (Winkelmann et al. 2022, §4.4). However, a recent review on the topic highlights a trend to overuse the concept of social tipping point, mainly as a consequence of a lack of epistemic caution: Milkoreit (2023) identifies in the literature a series of epistemically detrimental patterns in the application of the concept of social tipping points (such as premature labelling, definitional vagueness, lack of evidence). Moreover, part of the work on social tipping points is characterized by an overconfidence in our ability to understand the complexity of social systems and processes in terms a few control parameters (an attitude that Milkoreit 2023 finds "puzzling").

### 3.4 Imperialism of standing

Finally, the third aspect of scientific imperialism identified by Mäki (2013) concerns in particular the higher standing within ESS (in terms of prestige, power and political relevance) of certain quantitative methods (characteristic of the natural sciences) over more qualitative ones (typically found in the critical social sciences). This imperialism of standing is closely connected to the hegemony of what Heymann et al. (2017) call the "cultures of predictions"—an expression that aims to capture the various (political, cultural, economic,…) aspects linked to the production of predictive knowledge that relies on computer models.[11] Indeed, within these dominant cultures of predictions, they note that "[n]umbers generated with sophisticated scientific means such as computer models carry authority and represent powerful arguments in their own right", and this may lead to "the marginalization of the humanities vis-à-vis predictive scientific knowledge based on computer models and simulations" (Heymann et al. 2017, 8). This characterizes well the imperialism of standing at work within ESS, where modelling techniques play such a central and authoritative role, especially when it comes to policy making; for instance, Donges et al. (2020) are quite explicit about this role when they claim that "[c]omputer simulation models are pivotal tools for gaining scientific understanding and providing policy advice for addressing global change challenges such as anthropogenic climate change or rapid degradation of biosphere integrity" (396), where this modelling effort needs to extend to social processes in all their complexity in the new generation of World-Earth models (see section 1).[12]

[11] "While cultures of prediction emerged within scientific communities and built on scientific knowledge, they extend far beyond the realm of science and informed and shaped social practice, meaning and authority in broader society […]; we might say there is something *imperial* in the diffusion and dominance of certain predictive practices." (Heymann et al. 2017, 7, our emphasis) The "dominance of certain predictive practices" is also related to the imperialism of style within ESS we have discussed above (the aspects of 'scope', 'style' and 'standing' are interrelated).

[12] "Earth system analysis of the Anthropocene requires closing the loop by integrating the dynamics of complex human societies into integrated whole Earth system models […]. Such models need to capture the coevolving

Within the ESS framework, this imperialism of standing, as instantiated in these cultures of predictions, often implicitly involves a sort of epistemic injustice against social scientists (and against the humanities more generally), in the sense of a "credibility deficit […] making it more difficult for these scientists to function as a scientific expert" (Rolin 2018, 59), in particular when it comes to informing policy makers.[13] To some extent, there is an acknowledgement in parts of the ESS literature of the greater complexity of social processes (compared to physical ones) and of the challenges that mathematical representation and modelling face when it comes to human behaviour and social dynamics (Donges et al. 2020, 398; see also Winkelmann et al. 2022). However, the underlying assumption in ESS—which is little debated—still is that social processes can be quantified and predicted, and moreover that modelling is the best way to inform policy—at the expense of other forms of relevant scientific knowledge, in particular from the social sciences and the humanities. O'Brien and Barnett (2013, 384) thus argue that models in Earth system science (and a fortiori 'World-Earth system models') "do not accommodate lives, values, needs, rights, desires, loves, interests, and the workings of power in all its forms" and that "[t]hese cannot be subsumed into mathematical models and are instead unique forms of knowledge" about important features of social processes. They further highlight that "[t]he things that models do not account for are at best subordinate (or to be factored in if possible), at worst not matters of science, and hence, invisible in the science-policy process" (2013, 384). This invisibility in the science-policy process clearly constitutes a case of epistemic injustice in the sense of a credibility deficit (or unfair distribution of credibility)[14] towards the social scientists that produce and work on these "forms of knowledge". As a concrete example, we consider the fact that the ESS analyses of social tipping points (see §3.3) "tend to ignore existing social theories" (Milkoreit 2023) as exemplifying a form of epistemic injustice in the above sense, which itself can be understood as a consequence of an imperialism of standing of dynamical systems theory (among other related natural science disciplines) on critical theories of social changes.

In a first descriptive approach, we have seen in this section that the notion of scientific imperialism captures important features of the interdisciplinary relations at work within the ESS framework, in particular between natural and social sciences. We have also suggested how to apply in the ESS context various normative criteria that have been proposed in the philosophy of science literature on

dynamics of the social (the world of human societies) and natural (the biogeophysical Earth) spheres of the Earth system on up to global scales and are referred to as world–Earth models" (Donges et al. 2020, 396).

[13] A standard definition of epistemic injustice is "a wrong done to someone specifically in their capacity as a knower" (Fricker 2007, 1). In particular, we are here using Rolin (2018)'s closely related notion of "unfair distribution of credibility".

[14] Following Rolin (2018), a distribution of credibility is considered unfair in case there is a "mismatch between credibility and expertise".

interdisciplinarity (we will come back to this normative aspect in the last section). We now turn to the way the imperialistic nature of interdisciplinarity in ESS affects the articulation of values in this context.

## 4. Values in Earth system science

The role of so-called non-epistemic values in science, such as social, ethical, political and economic values, has been largely discussed in philosophy of science, in particular in relation to the value-free ideal of science and the challenge from inductive risk.[15] More specifically, the role of non-epistemic values in climate science has more recently attracted some increasing attention.[16] Within the framework of climate modelling, non-epistemic values have been convincingly argued to enter the picture at different stages in model development and model (output) assessment. For instance, non-epistemic values can have an influence in shaping model purposes and priorities, in selecting the entities and processes being represented as well as the way to represent them. Indeed, building and developing climate models involve numerous choices that are not fully constrained by theory or observation, thus leaving ample room for the influence of non-epistemic values. This influence has also started to be explicitly acknowledged in climate science in general (the role of non-epistemic values is explicitly discussed in the latest Working Group I report of the IPCC, see IPCC 2021). In this perspective, a crucial issue concerns the concrete management of non-epistemic values in climate science. Despite the fact that, in many ways, this issue has only been rather recently acknowledged, in particular at the concrete level of operational climate science, and thus requires further work, certain general features such as transparency and diversity have been argued to be key to legitimate value management in climate science (see, e.g., Intemann 2015, Jebeile and Crucifix 2021, Pulkkinen et al. 2022). In this context, transparency is about making explicit the underlying values and value judgements, while diversity concerns the plurality of values and perspectives (that is, also in terms of actors and communities).[17]

Now, we want to stress that, within the framework of ESS, the imperialistic nature of the interdisciplinary relations between the natural and social science domains may pose new challenges

[15] See for instance Longino (1990), Douglas (2009) and Elliott (2011, 2017) for some influential conceptions; see Eliott (2022) for a recent overview.

[16] See for instance Winsberg (2012), Betz (2013), Parker (2014), Intemann (2015), Parker and Winsberg (2018), and Frisch (2020).

[17] Transparency and diversity are of course related, as noted by Pulkkinen et al. (2022) in the climate context: "Diversity is important, because value judgements that are shared by a dominant majority can be rendered invisible. Where researchers come from a diverse set of perspectives, there is the opportunity to achieve greater objectivity by incorporating different perspectives, as is for example done by the IPCC's increasing inclusion of scientists from developing countries. Furthermore, it has been proposed that value judgements should be made transparent; they should reflect social and ethical priorities, and be scrutinized through engagement with multiple stakeholders". In particular, both transparency and diversity may help to acknowledge the values and interests of commonly underrepresented groups such as indigenous communities.

for implementing these features and for value management more generally. Indeed, transparency and diversity about values may be more difficult to achieve in a context of scientific imperialism, since certain values prevailing in the 'invading' discipline may be (more or less implicitly) imposed on the domain of the 'invaded' discipline. Within the framework of ESS, the hegemony of computer modelling methods for understanding both natural and social systems and the related cultures of prediction (which partake of both imperialism of style and imperialism of standing, see §3.3 and §3.4) may lead to the implicit imposition of certain technocratic values, according to which, for instance, climate and environmental challenges are best dealt with in exclusively techno-scientific and depoliticizing terms. As noted in section 2, this technocratic stance naturally "invites techno-managerial planning and expert administration at the expense of democratic debate" (Lövbrand et al. 2015, 217)—that is: at the expense of value diversity and transparency.

This lack of value diversity and transparency, which is strengthened by the scientific imperialism at work in ESS, lies at the heart of the homogenisation and depoliticization critique of the conceptual framework of ESS, and more particularly of the concepts of Anthropocene, planetary boundaries and tipping points (see section 2). It is for instance quite telling that the planetary boundaries framework still relies to a large extent on a value-free ideal of science where science alone is expected to unambiguously define a "safe operating space for humanity". However, the planetary boundaries framework clearly involves non-epistemic values at different levels, for instance when it comes to the various attitudes that can be adopted towards risks—defining what 'safe' means clearly involves values—or when it comes to the different possible trade-offs (or hierarchies) that need to be articulated between the different planetary boundaries (see Biermann and Kim 2020, Brand et al. 2021).

Proposals to expand the framework to include social boundaries—in order to define a "safe and just space for humanity" (Raworth 2012, 2017)—only strengthen the role of non-epistemic values, in particular when it comes to defining what counts as 'just' in this context. It is interesting to note that in recent years the ESS community has started to explicitly include a justice perspective in its approach to planetary boundaries (see recently Gupta et al. 2023, Rockström et al. 2023). In this context, an Earth system justice framework is adopted and operationalized in terms of three justice criteria, namely interspecies justice, intergenerational justice and intragenerational justice (see Gupta et al. 2023 for a discussion of Earth system justice in the ESS context). Rockström et al. (2023) convert these justice criteria into biophysical units in order to quantify "safe and just ESBs [Earth system boundaries] that minimize human exposure to significant harm […] from Earth system change". Non-epistemic values play an important role in the concrete articulation of these justice considerations, for instance in balancing between the different justice criteria; if this role is somewhat implicitly acknowledged in

the recent ESS literature, it is however explicitly put aside.[18] This move does not help managing values in this context; rather, it runs the risk of making their role (more) opaque and impeding value diversity, since value judgements are then made implicitly (or 'by default') and by a small number of experts.

To be clear: the issue here is not that non-epistemic values play a role in the planetary boundaries framework (this is to be expected), but rather the issue is the lack of value diversity and transparency, which raises a legitimacy question. Indeed, the value judgements (implicitly) made by the small number of experts—mostly natural scientists—designing the planetary boundaries framework may not be representative of the values and interests of the majority (or of the relevant stakeholders).[19] In the context of the operationalization of Earth system justice for planetary boundaries, Gupta et al. (2023) indeed "recognize that [they] have not adequately addressed recognition justice by including a broader representation of scholars or interested people in [their] selection of boundaries and research" (where recognition justice means including "the excluded and marginalized—women, indigenous people, local communities and developing countries, accounting for their views and ways of knowing").

This lack of value diversity and transparency leads to the implicit—and, in a sense, 'imperialistic'—imposition of certain values 'by default' that are embedded in the ESS planetary boundaries framework, such as those of the experts—who, as we have seen, are mostly natural scientists. Discussing this ESS framework from a critical social science perspective, Brand et al. (2021) thus argue that "the planetary boundaries concept limits its consideration to a rather narrow spectrum of values and worldviews" (268), and that it "risks reinforcing not only the invisibilization of other forms of knowledge […], but also the suppression of solution paths embedded in a plurality of ways of inhabiting the world […] by suggesting top-down technocratic solutions such as large-scale climate engineering" (273). This narrowing down of the space of possibilities ("solution paths") and of the space for debate is strengthened by the 'imperialistic' dominance of the natural sciences within ESS,[20] which tends to

[18] In their Methods section, Rockström et al. (2023) recognize that they "do not explicitly address possible trade-offs between the three justice criteria".

[19] A few dozen of experts, almost exclusively from the natural sciences and all working in institutions located in the Global North, were involved in the foundational paper on planetary boundaries (there is also a gender imbalance among the authors, see Rockström et al. 2009); the authors of the recent updated paper on "Safe and just Earth system boundaries" (a small number of which, including the first author, were already part of the original paper) also are natural scientists for the vast majority (they however display a greater geographical diversity, see Rockström et al. 2023). In recent years, work on planetary boundaries and Earth system justice (such as Gupta et al. 2023 and Rockström et al. 2023) has been produced within the framework of the Earth Commission network, which is hosted by the international science initiative *Future Earth*; these programs aim to foster interdisciplinary and transdisciplinary research on global sustainability issues (such as planetary boundaries), in principle also involving social and human sciences (for a discussion of the involvement of critical social science in this context, see Lövbrand et al. 2015).

[20] Brand et al. (2021) similarly argues that this technocratic bias "is not incidental, but rather is built into the planetary boundaries framework itself, in its view of the Earth from an "astronaut's eye view" that can only be provided by scientists". Of course, this is not to say that there is no room for improving value diversity and

leave unquestioned the linear model of the relationship between science and policy (according to which science provides value-free information for the policy-makers to follow). This linear model is contested in the social sciences (in particular in science and technology studies, e.g. see recently Jasanoff 2021a, b and Oreskes 2022) and in the next section we will consider alternatives that rely on more balanced interdisciplinary relationships (in particular between natural and social sciences) and on better value management (in particular promoting—rather than impeding—value diversity and transparency).

## 5. Perspectives

So far, we have investigated the nature of interdisciplinarity and the role of non-epistemic values in Earth system science (ESS), and we have argued in this context that the interdisciplinary relations between the natural and social science domains constitute a form of scientific imperialism. More specifically, we have seen in section 3 that the very global and unified ambition of ESS involves some degree of scientific imperialism from the natural sciences on the social sciences, in its dimensions of scope, style and standing. In this sense, this paper clearly identifies a novel and important case of scientific imperialism, which has not been discussed in the literature so far—Mäki (2013, 334) actually notes that the "empirical identification [of scientific imperialism] tend to be […] difficult".

This identification of scientific imperialism in ESS then raises the difficult question of its normative assessment. We have seen that certain normative criteria have been suggested in the literature on scientific imperialism (mainly in relation to the case of economics imperialism, see Mäki 2009, 2013, Clarke and Walsh 2009)—even if they do not all apply equally well to the ESS context. Various aspects of scientific imperialism as implemented in recent ESS developments can be epistemically harmful—and are therefore neither (epistemically) legitimate nor adequate—according to at least two normative dimensions: first, imperialism of style can lead to a lack of epistemic cautiousness (violation of Mäki's epistemological condition, see §3.3) and second, imperialism of standing may involve some level of epistemic injustice (see §3.4). Indeed, we have seen in §3.3 that the incautious application of mathematical and conceptual tools from climate science to social systems (e.g. concerning tipping points) can have epistemically detrimental consequences (see Milkoreit 2023). Similarly, we have argued in §3.4 that the cultures of predictions at work in ESS impose a credibility deficit on social scientists, which can lead to "impoverished accounts" of social systems and dynamics (see Rolin 2018).[21] These considerations point to the need for more balanced interdisciplinary relationships

transparency within ESS (and indeed the recent justice considerations in ESS do demonstrate that there is much room for improvement); however, it is crucial to identify and acknowledge the inherent normative dimensions of the ESS framework (see section 5).

[21] It is interesting to note that, according to Rolin (2018), in the context of scientific imperialism, both epistemic injustice and the violation of Mäki's epistemological condition have a *moral* as well as an epistemic component:

within ESS, in particular between the natural and social science domains, that is, to the need for a more legitimate scientific imperialism in ESS.[22]

One strategy to move towards a more balanced interdisciplinarity within ESS is to explicitly take into account value management alongside other normative criteria that are relevant for scientific imperialism in ESS (such as Mäki's epistemological condition and Rolin's fair distribution of credibility).[23] As already mentioned, providing a full set of necessary and sufficient conditions for scientific imperialism to be legitimate (and adequate) in ESS seems rather difficult since much depends on the concrete details of the specific situation under consideration (so that a detailed evaluation is very much a case-by-case issue). The suggestion here is to highlight value management as a central aspect of balanced interdisciplinary relationships in ESS:[24] interdisciplinary relations—including imperialistic ones—must help promoting—instead of impeding—legitimate value management, which may typically involve value diversity and transparency (see section 4).

Recent work in philosophy of science on values (see Elliott 2022 for an overview) can help to shed some light on ways to implement (legitimate) value management within ESS. For instance, Elliott (2017, 2022) suggests three conditions for guiding value management in science:[25]

> (1) Transparency: "scientists should be as *transparent* as possible about their data, methods, models, and assumptions so that others can identify the ways in which their work supports or is influenced by particular values" (2017, 14).
>
> (2) Representativeness: "scientists and policymakers should strive to incorporate values that are *representative* of major social and ethical priorities" (2017, 14).
>
> (3) Engagement: this condition "focuses on generating engagement between different scientists, community members, and scholars from range of different fields" (2022, 46). In particular, this condition involves promoting diversity.

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indeed, epistemic injustice gives rise to an unfair (and hence morally wrong) distribution of credibility and a lack of epistemic caution may have morally harmful consequences.

[22] One may be tempted to try to get rid of scientific imperialism altogether; however, it is important to remember that scientific imperialism as characterized here is not necessarily a bad thing, and can indeed be epistemically beneficial (Mäki 2013). Moreover, to a certain extent, some level of scientific imperialism seems constitutive of what ESS is in the first place.

[23] Beside the ontological and epistemological constraints discussed in section 3, Mäki (2013) suggests two other—axiological and institutional—constraints on scientific imperialism. According to the axiological constraint, the explanatory gain of scientific imperialism should involve morally and socially significant phenomena. The institutional constraint concerns the social epistemology aspects of good scientific practice. These constraints also somewhat implicitly involve non-epistemic values in different ways. Our proposal here is to put value management at the heart of legitimate scientific imperialism.

[24] We are interested in and focus on ESS here, but the highlighted relevance of value management for interdisciplinary relations (and scientific imperialism in particular) has a wider scope.

[25] To a certain extent, these conditions bring together elements from other proposals in the literature (Elliott 2022, §4).

According to Elliott (2022, 46-47), condition (3) emphasises the importance of "generating communication between an interdisciplinary array of scholars in order to promote critical reflection on values in science"—in particular, such a reflection is typically pursued within critical social sciences, as we have noted in section 3 (see footnote 10). So, our suggestion here that the issues of value management and interdisciplinarity are interconnected and best addressed together is thus very much in line with Elliott's account of value management. Now, to concretely implement Elliott's conditions (1)-(3) within the framework of ESS raises a number of tricky questions (some of which being related to general issues identified by Elliott himself, independently of the ESS context). For instance, to what extent and how exactly should transparency be implemented? (As Elliott 2022, 47 puts it: "[t]ransparency can never be achieved perfectly, and it has costs as well as benefits […], so it is important to specify more precisely how to achieve the kinds of transparency necessary for managing values appropriately.") When it comes to the representativeness condition, identifying "major social and ethical priorities" in the global context of ESS is extremely challenging. And similarly, identifying who is entitled to take part in the engagement effort and under what conditions is not easily answered at the scale of the entire planet (for instance, power relations among stakeholders need to be carefully considered at this scale, see also footnote 27). More specifically, how to engage with indigenous and other subaltern communities around the world, their priorities and values is indeed extremely challenging. All these questions relate to difficult and open issues about values in science that are subject to intense on-going research (see Elliott 2022 for an overview), and addressing them in depth would go much beyond the scope of this paper (but constitutes an important task for future work).

What we want to stress is that fostering legitimate value management within ESS in the sense of implementing Elliott's conditions of transparency, representativeness and engagement involves recalibrating interdisciplinary relations—including imperialistic ones—within ESS. Indeed, implementing condition (3) above requires ESS to engage with a "range of different fields", in particular including (critical) social sciences when it comes to generate "critical reflection on values" in ESS. This engagement can take many different forms and take place at different levels. As an example, the international science initiative *Future Earth* precisely aims to provide an institutionalized framework for such an interdisciplinary engagement.[26] This latter puts severe constraints on scientific imperialism in ESS: while great epistemic caution is required along the dimensions of scope and style, imperialism of standing seems incompatible with value diversity and interdisciplinary engagement (in particular so

[26] The Mission and Objective statement of *Future Earth* reads the following: "Future Earth convenes researchers and scholars from all parts of the world, across different societal and academic sectors, and across the natural, social, and human sciences. Future Earth initiates and supports international collaboration between these researchers and stakeholders to identify and generate the integrated knowledge needed for successful transformations towards societies that provide good and fair lives for all within a stable and resilient Earth system." (https://futureearth.org/)

as to avoid all forms of epistemic injustice, see §3.4). In this perspective, the pursuit of explanatory unification and the transfer of concepts and methods form one discipline to another within ESS need to make explicit their limitations and allow for critical reflection on values in ESS—but should not lead to a higher standing or any form of hegemony of the 'imperialist' concepts and methods.

We would like to end with a few considerations about ways forward inspired by recent works in science and technology studies (STS) on how science should best address the global climate and environmental challenges. Indeed, Inkpen and DesRoches (2019) emphasize interdisciplinarity and values as central features of what they call "science in the Anthropocene", since the Anthropocene confronts natural and social scientists with "problems and systems that transgress traditional disciplinary boundaries" and since, at the same time, the Anthropocene also "increasingly involve[s] discussions that inextricably link the normative and the scientific". This latter link is also at the heart of Jasanoff's co-production framework, which rests on "the observation that how we acquire and organize our knowledge of the world is always entangled with ideas of how we should govern it" (Jasanoff 2021a)—ideas which of course fundamentally involve value issues. Co-production in this sense is a central feature of knowledge production within the framework of ESS: as a paradigmatic example, the global ESS perspective naturally involves the concept of Earth system stewardship, that is, the idea of steering the Earth system on a 'safe' planetary trajectory (in an abstract planetary state space), away from dangerous potential planetary tipping points (see Steffen et al. 2018). Of course, such a planetary stewardship fundamentally involves value considerations, as the value-laden notions of 'safe' and 'dangerous' clearly illustrate; it also raises the issue of legitimate value-management in a particularly acute manner, since the values of the experts involved in steering the Earth system may play a disproportionate and illegitimate role.

From a co-production perspective, the issues of values and of value management are therefore central to the enterprise of scientific knowledge production: in the context of climate science, Jasanoff (2021b) recently argues for questions of justice to be at the heart of the climate knowledge-making process (according to her, it is crucial to ask questions such as: "how might knowledge-making be made more compatible with society's demand for just climate policies?"). In the context of ESS, acknowledging co-production similarly entails seriously (and openly) debating over the (ethical, political, social, economic,…) values to be promoted, and interdisciplinary engagement (in Elliott's sense) provides favourable conditions for such a debate.[27] As Inkpen and DesRoches (2019) put it:

[27] The co-production framework and the interdisciplinary engagement should pay carefully attention to the power relations among the various stakeholders involved in order to avoid creating or reinforcing existing inequalities and epistemic injustices (see Daly and Dilling 2019 for an interesting case study of the role of power relations in the 'co-production' of usable climate services; see also Dilling and Lemos 2011 about the

"[m]oving forward, natural scientists need to more fully embrace their colleagues in the social sciences and humanities who are specifically trained to deal with such [value] issues."[28] We have argued that this very much applies to ESS.

Much work remains to be done within ESS to address the issue of value management and to recalibrate interdisciplinary relations accordingly, including in their imperialistic dimensions inherent to ESS. Given the scientific ambitions of the field (e.g. fully integrating social systems into the Earth system description) and its normative ramifications (e.g. in terms of planetary stewardship), the interrelated value and interdisciplinarity challenges are especially acute and pressing in ESS, in particular when it comes to articulate the influential—in the co-productionist sense—concepts of Anthropocene, planetary boundaries and tipping points. As Brand et al. (2021, 280) put it, "[n]o one discipline or approach is afforded the luxury anymore of pretending that its findings are not political".

Acknowledgements

We are grateful to the audiences in Geneva (Quodlibeta) and Belgrade (EPSA23), and acknowledge support from the Swiss National Science Foundation professorship grant PP00P1_211010. YR is grateful to the Faculty of Humanities of the University of Bern for partial financial support ('Seed Money').

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features of the iterativity process involved in the co-production of usable climate knowledge). We are grateful to an anonymous referee for highlighting this point to us.

[28] Concluding his grand history of science study on the evolution of human knowledge, Renn (2020, 415-416) argues in a similar vein that, "in confronting the Anthropocene, we should reorient the current knowledge economy toward global responsibility", and that this transformation "will have to include […] the interlocking of multiple knowledge dimensions, and critical engagement with the entanglement of knowledge with political, economic, and moral issues—these are the hallmarks of science in the twenty-first century."

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