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From Earth system science to Earth system law: Enabling a new legal paradigm for the Anthropocene

De la ciencia del sistema Tierra al derecho del sistema Tierra: Permitiendo un nuevo paradigma jurídico para el Antropoceno

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Abstract

Earth system science has shown that the Earth's life-enabling conditions rely on its interconnected, complex, adaptive system composed of natural processes, biogeoechemical cycles, and energy fluxes. Although Earth's future depends on maintaining this system in a well-functioning and stable state, to date, the law fails to effectively protect it. Earth system law has recently been proposed as a new legal paradigm able to embrace the complexity and non-linearity underlying the Earth system functioning. In exploring the normative aspects of the Earth system this paper proposes a conceptual framework that integrates three aspects for strengthening the law's role in protecting the Earth system: adaptiveness, systems regulation, and planetary justice. Ultimately, this paper discusses the implications for Earth system law to integrate adaptiveness, systems regulation, and planetary justice and protect the planetary conditions that sustain all life forms.

Keywords

Earth system law; Earth system governance; Earth system science; Planetary Justice; Environmental Law.

Resumen

La ciencia del sistema Tierra ha demostrado que las condiciones necesarias para sostener la vida en la Tierra dependen de su sistema interconectado, complejo y adaptativo, compuesto por procesos naturales, ciclos biogeoquímicos y flujos de energía. Aunque el futuro de la Tierra depende de mantener este sistema en un estado funcional y estable, hasta la fecha, el Derecho no ha logrado protegerlo eficazmente. Por tal razón, el derecho del sistema Tierra se propone como un nuevo paradigma jurídico capaz de abarcar la complejidad y no linealidades subyacentes al funcionamiento del sistema Tierra. Al explorar los aspectos normativos del sistema Tierra, este documento propone un marco conceptual que integra tres aspectos para fortalecer el papel de la ley en la protección de dicho sistema: adaptación, regulación de sistemas y justicia planetaria. En última instancia, este artículo discute potenciales implicaciones dentro del marco del derecho del sistema Tierra para integrar la adaptación, la regulación de sistemas y la justicia planetaria como pilares necesarios en la protección de las condiciones planetarias que sostienen todas las formas de vida.

Palabras clave

Derecho del sistema Tierra; Gobernanza del sistema Tierra; Ciencia del sistema Tierra; Justicia Planetaria; Derecho ambiental

I. Introduction

Earth system science has allowed us to understand that the Earth is more than just a planet (referring to its tangible aspects). Earth system is defined as an interconnected, complex, adaptive system composed of processes, cycles, and fluxes that allow all life on Earth (Magalhães, 2020; Steffen et al., 2020). Nevertheless, human activities have had major impacts on the Earth system and have structurally modified those conditions that support all life forms (Steffen et al., 2005).[1] While Earth system science has been concerned with numerous aspects related to a changing Earth system for several years now, the integration between the natural and social sciences that is necessary to address this global challenge, has not yet been achieved to the extent required (see e.g. Kim and Kotzé, (2020); Steffen et al., (2020)). One major concern arising from this lack of interdisciplinarity and co-learning is that, despite a deeper scientific understanding of the Earth system, law, and environmental law specifically, has not been able to embrace and respond to these new insights (Kotzé, 2019). Environmental law instead continues to regulate and limit human activities in the context of outdated ecological realities for instance, by controlling water access according to the water sources monitoring of previous years and without considering the hydroclimatic variables.

If there are no substantial changes in how the law regulates human actions, for instance, by acknowledging their destabilising effects on the Earth system, it is

[1] Steffen, W., Sanderson, A., Tyson, P., Jäger, J., Matson, P., Moore, B., Oldfield, F., Richardson, K., Schellnhuber, H.J., Turner, B.L., Wasson, R.J., 2005. Global Change and the Earth System: A Planet Under Pressure, Global Change — The IGBP Series. Springer Berlin Heidelberg, Berlin, Heidelberg. https://doi.org/10.1007/b137870.

improbable that the law will be an effective tool to protect Earth's life-enabling conditions. As a response to this challenge, the notion of Earth system law has recently been proposed as a new legal paradigm relevant to the attempt to regulate human interactions with the Earth system, that is, with the tangible and intangible conditions that support life itself (Kotzé and Kim, 2019).

Drawing on the domains of Earth system science, Earth system governance, and environmental law, this paper identifies three core challenges that current environmental law fails to address. Firstly, the complex-adaptive nature of the Earth system; secondly, the feedback and destabilising effects that human activities have over the Earth system processes and conditions; and thirdly, an equitable distribution of ecosystem services and resources among all the constitutive components of the Earth system to maintain Earth's safe operating conditions (Kotzé, 2019; Lopez Porras, 2020). These problems (individually and collectively) are a common denominator in our socio-ecological crises and Earth's present decay. From this perspective, this paper proposes a conceptual framework built on three core aspects that an Earth system notion of law should embrace to provide suitable legal responses to the challenges mentioned above. These aspects consist of adaptiveness, systems regulation, and planetary justice. Although such aspects have been identified by literature as critical for improving governance in the Anthropocene (Burch et al., 2019), it is still unclear how the law, a social construct designed to guide human behaviour, can integrate them to protect the Earth's stability and well-functioning. If the law embraces such critical aspects, it will increase its potential to integrate insights provided by the Earth system science and achieve new notions of "rule of law"[2]; that better fit Earth system paradigm.

Accordingly, this paper explores the implications for environmental law to integrate an Earth system perspective (including scientific insights) through the lenses of adaptiveness, systems regulation and planetary justice, to move towards Earth system law. The discussion commences by reflecting on the prevailing disconnect

[2] In the light of the complex socioeconomic and environmental interplay taking place, Brown & Garver (2009) say that we need a more scientific-based rule of law. Considering current unsustainable pathways and according to the authors, the rule of ecological law "it means that global regulatory limits required to meet ecological limits and ensure fair sharing of the earth's bounty must be respected" (p. 135).

between Earth system science and environmental law.[3] Indeed, section 2 shows that environmental law has not yet benefitted from Earth system science insights and is unable to respond to the challenges that arise from the complex and adaptive nature of the Earth system. Then, section 3 discusses the concept of Earth system law, its scope and introduce the three core pillars proposed in this conceptual framework (adaptiveness, systems regulation, and planetary justice). Finally, the last section investigates how those three pillars could be integrated into further legal development for embracing an Earth system perspective and protecting the Earth system.

II. The disconnect between Earth system science and environmental law

Earth system science shows that the Earth is "a single, planetary-level complex system, with a multitude of interacting biotic and abiotic components" (Steffen *et al.*, 2016, p. 325) and that humans are the main drivers of Earth system change (Steffen *et al*., 2020). Earth system research has primarily advanced in the domain of the natural sciences, while endeavours to integrate the Earth system perspective into the social sciences are more recent and face different challenges (Burch et al., 2019). A critical challenge in this respect is that some processes, cycles, and fluxes that contribute to maintaining the Earth system in a Holocene-like state,[4] do not exist from a legal standpoint and remain mostly invisible in our legal frameworks (Magalhães, 2020).[5] To this end, the social sciences have not matched advances made in the natural sciences regarding Earth system literature. The collaboration and coordination of the natural and social sciences are of vital importance if we are to address the Anthropocene and prevent further decay of the Earth. Social

[3] In this paper, environmental law does not refer specifically to international or domestic environmental legislation, but more generally, to the area of law that protects the environment.

[4] The Holocene is the geological epoch that, given its relatively stable planetary conditions, is "the only state that we know for certain can support agriculture, settlements and cities, and complex human societies" (Steffen et al., 2020, p. 60)

[5] As defined by North, (1991) institutions are social devised constraints that establish and structure human interactions. Such institutions can be informal (e.g., traditions and perceptions) and formal (e.g. laws and policies). In this sense, this paper foresees the law as an institution that constraints human interactions.

scientists must better understand Earth system dynamics and their links with humans to identify better legal and policy responses for the Anthropocene.

For example, the planetary boundaries framework shows the levels of human disturbance that the Earth can absorb if it is to remain stable (Steffen *et al*., 2015). Yet, the constraints devised for regulating human activities that impact the Earth system do not aim to contain such human activity within a safe operating space. We are now aware of the complexities of the relationship between the interlinked biogeochemical and human processes leading to Earth's decay (Shapiro *et al.*, 2010). However, advances in our understanding of the Earth system have not been accompanied by the necessary institutional changes that would necessarily lead to its protection. Greater interdisciplinary in Earth system science must therefore be achieved so that natural scientists can identify problems and propose solutions, while social scientists can translate and realise these through appropriate tools (such as the law) to improve the regulation of human activities (Sterner *et al.*, 2019).

One clearly observes this disconnect between the natural science and social science domain in the area of environmental law. Environmental law is a crucial part of the social regulatory institutional mix aimed at regulating human behaviour towards the environment to protect and restore it if it has been affected (Khalatbari and Abbas, 2019). However, given its anthropocentric (human-centred), reductionist (address complex problems in terms of its simple constituents) and linear (conceives dynamics as consistent and stable) nature, environmental law is fundamentally unable to address the complex socio-ecological challenges posed by the Anthropocene, and unsuitable as an institutional tool for protecting the Earth system (Kotzé and Kim, 2019). Currently, environmental law does not embrace the complexity and non-linearity required for navigating the Anthropocene nor recognise the processes and life-generating conditions that make up the Earth system (Magalhães, 2020). Therefore, the Earth system remains out of the law's scope, not properly regulated, and indiscriminately degraded.

Given the complex-adaptive nature of the Earth system identified by current scientific endeavours, it is now possible to better understand the regulatory failures of environmental law. Indeed, current environmental law's inability to fully embrace complexity and interconnectivity is observed in the lack of legal provisions and

tools required by vulnerable communities to enable them to adapt to climate change (Marjanac and Patton, 2018), and in the lack of consideration of the adaptive cycles and slow variables when limiting and regulating, for example, fisheries, forestry or agroecosystems, leading in many cases to environmental depletion (Gunderson *et al.,* 2010, 2016). Indeed, a significant obstacle to increasing environmental law's capacity to transform and adapt to the complex-adaptive nature of the Earth system is the lack of engagement of non-state actors in law compliance and enforcement (Garmestani *et al.,* 2019). Other regulatory failures of environmental law derive from its lack of a scale (e.g. spatial and temporal) and level (e.g. global and local) perspective (Garmestani *et al.,* 2019). Currently, environmental law does not foresee or regulate the socioeconomic and environmental interactions at different jurisdictions, between different international actors (also known as telecouplings (Liu *et al.,* 2013)), which has resulted in injustices and impacts on human rights and the environment at a local and regional level and scale. For instance, in Mexico, foreign mining companies have polluted local communities' water resources and altered the water cycle that maintains the functioning of local freshwater systems; at the same time, such companies have been transgressing local human rights and compromising local livelihoods (Alfie Cohen, 2015; Stoltenborg and Boelens, 2016).

Another significant regulatory failure consists of the inability of environmental law to integrate all the Earth system components into the purview of justice. The type of justice provided by environmental law settles issues only between humans with little or no regard for non-human entities, hindering the legal protection and maintenance of nature's welfare (Parris *et al.*, 2014). The protection of the Earth system is vital to the continuity of all life, and yet traditional notions of environmental justice seek to achieve only an equal distribution of environmental costs and benefits; and even this, it has not managed to do successfully as the most vulnerable and poor communities are commonly those responsible for the bulk of environmental costs (Deane-Drummond, 2012; Lecuyer *et al*., 2018). For instance, in Southeast Asia the forestry, mining and water sectors have generated unequal distributions of costs and benefits as well as violations of human rights and irreparable and unattended environmental harms such as water pollution and loss of biodiversity (Pichler and Brad, 2016).

Any notion of justice for the Anthropocene must conceptualise the complexity of the socio-ecological interplay inherent to the Earth system by recognising that both humans and non-humans (i.e., river basins) are indispensable to our collective future (Gürcan, 2019). Furthermore, any environmental notion of justice must embrace the Earth system conditions required for all life forms to exist and flourish, so the cycles and structures that make up the Earth system can be within the scope of justice (Lopez Porras, 2020). Since environmental law does not embrace complexity and uncertainty, it does not acknowledge the relatively stable planetary conditions critical for sustaining different life forms (Lopez Porras, 2020). The only certainty to be found in the continued application of environmental law is that the present trends will continue. In this scenario, the Earth system will inevitably cross planetary tipping points, suffering unplanned and undesired alteration on the conditions that enable life, and that maintain its relatively stable Holocene-like state (Kotzé and Kim, 2019). Thus, developing an Earth system-oriented law that is more appropriate for the Anthropocene context is central to the attempt to guarantee the continued existence of all living forms and protect the Earth system's components.

III. Earth system law

Earth system law has been proposed as an alternative legal paradigm to strengthen the protection of the Earth system by addressing the complex, multi-form, multi-scale (spatial and temporal) issues arising from the need to regulate the social and ecological interplay (Kotzé and Kim, 2019). Earth system law is defined as:

…an innovative legal imaginary that is rooted in the Anthropocene's planetary context and its perceived socio-ecological crisis. Earth system law is aligned with, and responsive to, the Earth system's functional, spatial and temporal complexities; and the multiple earth system science and social science-based governance challenges arising from a no-analogue state in which the Earth system currently operates. Earth system law seeks to respond to the Earth system's instability and unpredictability through a continuous norm development process that drives meaningful transformations as well as interdisciplinary learning and deliberation (Kim and Kotzé, 2020, p. 11).

Nevertheless, to increase its comprehension, applicability and use, Earth system law could benefit from a more concise definition and scope. Firstly, the Earth system is defined as the suite of biogeochemical cycles and energy fluxes (including their natural variability and temporal and spatial complexities) that provide the necessary conditions for enabling life on the planet (Steffen et al., 2005). Accordingly, maintaining the biogeochemical cycles and energy fluxes conducive to those favourable planetary conditions that sustain all life forms and allow human societies to flourish is the primary interest and rationale behind the scientific endeavours to protect the Earth system (Schellnhuber, 1999; Steffen et al., 2020). However, human activities increasingly destabilise such biogeochemical cycles and energy fluxes, pushing the Earth out of safe operating conditions towards uncertain and dangerous operating conditions for many life forms (Steffen et al., 2015). This situation remains unaddressed (and poorly regulated), principally because such planetary conditions (made of cycles, processes and fluxes) are hardly visible to our institutions (e.g. the law (Magalhães, 2020)). However, thanks to Earth system science, such (safe) planetary conditions are qualitatively definable and quantitatively measurable (Gleeson et al., 2020; Steffen et al., 2015). Accordingly, it is now possible to obtain the scientific and technical support for establishing the required legal prescriptions to act regarding the Earth system for its protection. Therefore, to fill the legal gap regarding the poorly regulated interactions between humanity and the other constitutive elements of the Earth system, this paper defines Earth system law as the legal science that studies the normative aspects of the human interactions with the cycles, processes and fluxes that are critical for maintaining the Earth system in a safe state for all life forms.[6] In view of the above, this legal reflection is initial or preliminary, requiring subsequent explorations and practical discussions to facilitate its progress at a normative level. As discussed above, its autonomy from other legal fields, such as environmental law, lies substantially in the ontological conflict that exists between the anthropocentric paradigm and that centred on the Earth system. Likewise, since Earth system law is still at a very

[6] Here, legal science is defined as the activities carried out by scholars, scientists and law practitioners, and the methodological assumptions governing these activities (Núñez Vaquero, 2013, p. 56). Although the aim is to achieve formality and enforcement of Earth system law, currently it cannot be defined as an area or field of law, neither as a legal regime; for which it holds the status of legal science.

theoretical stage, subsequent discussions require further exploration of both the implications this would have on the relationships that take place between States (within the international law) and its contrast with current international treaties, as well as the relationships between citizens and their government (domestic), and the legal provisions that can be leveraged for its formalization.

In this sense, the purpose of Earth system law would be to be adaptive to the complex-adaptive nature of the Earth system, regulate human behaviour, so it does not destabilise the Earth's structures and conditions, and ensure equitable distribution of resources and ecosystem services to maintain the Earth's safe planetary conditions.

The previous section described environmental law's inability to embrace the Earth system's complex and non-linear nature, regulate cross-level and cross-scale interactions, and provide justice from an Earth system perspective. So, what is next, is to describe the relevance of the elements in this conceptual framework for overcoming such legal challenges and provide required legal responses to the Earth system's needs. The following subsections explain the role of adaptiveness, systems regulation, and planetary justice in Earth system law, which are further discussed in this paper's final section.

1. Adaptiveness

Adaptiveness (an umbrella term encompassing different but related concepts such as adaptive capacity and resilience) here is defined as the social and institutional ability to change in the face of uncertainty so that the system can maintain the stability required by all life forms (Burch *et al*., 2019; Gunderson *et al*., 2010; O'Connell *et al*., 2016). This conceptual lens aims to allow Earth system law 1) to enable societal capacity to change unsustainable pathways, and 2) to be a new legal paradigm itself adaptive when formal changes are required. In this sense, adaptiveness is divided into two aspects: societal adaptiveness and institutional (legal) adaptiveness (Lopez Porras et al., 2019).

Societal adaptiveness encompasses those processes of social change designed to maintain the system's state (its structure, feedbacks and functions) or to change it when it becomes untenable and/or endangers the subsistence of other species

(Lopez Porras et al., 2020a; O'Connell et al., 2016). There are dynamics and conditions that can lower or increase societal adaptiveness. Top-down approaches of governance (that hinder decision-making and the design of laws and policies at the level where socio-ecological needs emerge), conflicts over access of scarce resources, lack of connectivity and collaboration between stakeholders are characteristics of low societal adaptiveness (Chaffin et al., 2014; Lopez Porras et al., 2020b). As an example, Chaffin *et al.* (2016) explain how centralised water management and social conflicts hinder legal compliance and undermine the social capacity to address and adapt to ecological problems, such as the intensification of toxic algae that affects the socio-ecological interplay. Conversely, flexible formal arrangements (at the level where social and ecological needs concur), iterative (so they can be adjusted in the light of new information), and with the required access to economic and institutional resources for their design and enforcement, are features of high societal adaptiveness (Hill Clarvis et al., 2014; Lopez Porras et al., 2020b). Sarker (2013) reports how adaptive management and stakeholder collaboration supported by legal, political, and financial resources provided by the government foster societal adaptiveness, even when there is a resource shortage, by enabling management arrangements at the watershed scale. Accordingly, Earth system law should provide a suitable setting that fosters societal adaptiveness, for instance, by enabling stakeholder collaboration and access to legal and policy resources essential in highly adaptable systems.

In light of the above, the conceptual lens of adaptiveness integrates four principles that Earth system law should embrace for enabling such notion of (societal and institutional) adaptiveness. The first principle is 'connectivity and subsidiarity', which refers to local legislation and policies that establish locally appropriate normative structures, and enable cross-level engagement between different actors, so they concur to better address context-specific needs at a local (or most suitable) level (Lopez Porras et al., 2019). The second principle is 'legally binding authority and accountability' consisting of the endowment of formal authority to local, organised, and structured groups of state and non-state actors to make and implement decisions and enforce the law. These actors will be accountable for the group's actions (DeCaro et al., 2017). The third principle is 'financial, technical and administrative resources', which is the support and mechanisms that local state and

non-state actors require to meet their legal responsibilities and conduct actions to increase societal and institutional adaptiveness (DeCaro et al., 2017; Lopez Porras et al., 2019). The fourth principle is 'iteration and flexibility', consisting of the ability to efficiently adjust the law according to ecological conditions and societal needs in fixed time-bound review periods to regulate the non-linear socio-ecological interplay better while creating the formal conditions that foster adaptiveness (Hill Clarvis et al., 2014).

Because "the macroscopic properties of complex-adaptive systems emerge from lower-level interactions" (Levin *et al*., 2013, p.114), it is highly improbable that top-down and centralised laws and institutions will effectively support adaptiveness. Earth system law must guide human actions away from current Earth system destabilisation trends. Doing so requires subsidiary and iterative provisions that allow designing adaptive and strategies at the most suitable socio-ecological scale. Earth system law must embrace the principles of adaptiveness to overcome the law's state-centric and linear nature, which hinders adaptiveness from facing critical ecological (e.g. droughts, wildfires, pollution) and societal (e.g. corruption, human rights violations, unequal distributions of costs and benefits) stressors, and to change unsuitable development pathways (DeCaro et al., 2017; Hill Clarvis et al., 2014; Lopez Porras et al., 2020b).[7] By embracing the adaptiveness proposed in this conceptual framework, Earth system law will increase its potential to fit itself and adapt human activities within the processes, cycles, and fluxes that keep the Earth system stable and well-functioning.

2. Systems regulation

Since the Earth system is of a complex system, there are cross-scale (e.g., spatial and temporal scales) and cross-level (e.g., daily socio-ecological interactions at a local level shaping seasonal dynamics at the regional level) dynamics that play a critical role in the functioning of the cycles, processes and fluxes that maintain the Earth in its Holocene-like state (Steffen et al., 2005). Nonetheless, the negative effects that human activities have over those complex dynamics, which ultimately destabilise the Earth system are poorly regulated. For instance, the chemical

[7] A societal stressor is a condition, event, or trend that systematically affects human well-being and social functions, undermining its adaptive capacity (Lopez Porras et al., 2020a).

composition of the Earth system mainly relies on the planetary life structure that influences the exchange of energy fluxes through the generation, dissipation and transfer of free energy (Kleidon, 2012). However, current unsustainable growth increases the demand for such free energy. When we take the Earth's free energy sources to meet human needs, the Earth's ability to produce free energy decreases (Kleidon, 2012). Protecting the Earth's chemical composition requires better regulating human feedback effects on the planetary life structure and energy fluxes; for doing so, this paper proposes the concept of systems regulation.

Systems regulation refers to the law's ability to regulate human activities according to their destabilising effects on the Earth system functioning. Systems regulation would focus on two aspects that current environmental law fails to do correctly:

The cross-scale and cross-level distant interactions taking place within the Earth system (Du Toit et al., 2021).

The ecological structures, processes and cycles on which human dynamics need to fit within (Levin et al., 2013; Wackernagel et al., 2021).

Regarding impacts between remote systems, current international socioeconomic interactions (e.g. the production of goods, trade, or the exploitation of resources) have many adverse multi-level effects on the Earth system that are not adequately regulated (Hey, 2021). These "socioeconomic and environmental interactions among coupled human and natural systems over distances" are also known as "telecouplings" (Liu et al., 2013, p. 3) and the main reason why the law fails to properly regulate them is its lack of a "scale and level" perspective (Garmestani et al., 2019). Accordingly, the telecoupling framework can provide a valuable lens to analyse and better regulate such complex, distant interactions within the Earth system. Its relevance relies on breaking down such socio-economic and environmental interactions into systems (divided into sending, receiving, and/or spill-over systems), flows (the connection between systems), agents (they facilitate or hinder the flows and may consist of corporations or governments), causes (they produce the telecouplings and generate the effects), and effects (environmental or socio-economic (Liu et al., 2015)). Therefore, it provides

a comprehensive understanding of systems' interactions and their feedback effects that will enable us to regulate them more efficiently.

To illustrate how it works, Liu et al., (2013) explain the destabilising effects between an increasing export of soybean from Brazil and China due to a trade agreement. There, Brazil and China are identified as 'systems', soybeans and money as 'flows', farmers, companies and government as 'agents', and China's demand for soybeans and Brazil's interests to have international trade agreements as 'causes'. However, to meet China's requirements of soybean, Brazil increased Amazon deforestation, the use of herbicides, pesticides and fertilisers, which ultimately resulted in the loss of a critical biome and ecosystem services, the displacement of local people, and rural violence (Liu et al., 2013). These are the 'effects' of such trade agreements. That is, the result of cross-scale (between jurisdictions) and cross-level (an international agreement impacting local livelihoods) interactions between remote systems. From the lens of systems regulation, soybean export should be limited according to the effects of its production on the Amazon system (which includes its inhabitants). Accordingly, the telecoupling framework is a beneficial lens to move towards that direction, even with interactions between sub-systems at a lower level, but that can still be identified by their flows, agents, causes, and effects. Nevertheless, as systems regulation refers to the law's ability to regulate human activities according to their feedback effects over the Earth system, there is one missing aspect to discuss: the ecological structures, processes and cycles on which human dynamics need to fit within.

Human activities are increasingly destabilising the ecological structures (e.g. heterogeneity), cycles (e.g., water cycle), and processes (e.g., carbon sequestration) to optimise profit (Levin et al., 2013). This is evident, for example, by observing how the decline of fish and marine life due to overfishing destabilises the ocean's functioning, and increases its acidification (Sala et al., 2021). Afterwards, climate-related drivers such as increasing temperature and ocean acidification also negatively affect the number and compositions of marine species. As a result, fishing companies can cross ecological thresholds more easily, which will lead to the extinction of marine species and international conflicts over scarce resources (Werrell and Femia, 2017). Therefore, fish (and marine life in general) should not be regulated only by their stock, as if their decline or depletion would be only

the disappearance of an object or the exhaustion of a resource. They should be regulated to fit within the oceans' structures, processes, and cycles.

A significant challenge against achieving such regulatory effectiveness relies on the mismatch between how social and natural scientists analyse global problems, which structurally decouples the social (e.g. laws and policies) from the ecological and hinders our ability to regulate human activities from an Earth system perspective (Cardesa-Salzmann and Cocciolo, 2019; Otto *et al.*, 2015). However, systems regulation is proposed as a conceptual lens to bring together this required interdisciplinarity into regulatory prescriptions. Therefore, enabling a new notion of Earth system law to adjust current unsuitable socioeconomic dynamics (e.g., production and consumption patterns) so they can be compatible with the Earth's Holocene-like state. For doing so, systems regulation explicitly recognises that coupled socio-ecological systems co-adapt in their ecology and socio-economic portfolios (Stringer et al., 2017) and establishes regulations that will prevent development pathways from crossing an ecological threshold.

For instance, regulating agricultural feedback effects not to cross dryland ecological thresholds and increase desertification, requires adjusting agricultural practices according to the interaction between slow (e.g. soil erosion) and fast (e.g. precipitation) ecological variables (Lopez Porras, 2021a). Furthermore, such regulations need to restrict maladaptive strategies, like increasing the agricultural frontier or water overexploitation, when ecological structures and conditions cannot sustain crop yields (Lopez Porras et al., 2020a). As shown in the previous example, an effective Earth system rule of law requires regulations that foresee cross-scale and cross-level interactions and restricts them on the ecological reality. This way, the rule of law can guarantee that human activities do not surpass the structures, cycles, and processes that maintain system stability. Through systems regulation, Earth system law has the potential to do so, which lead us to the third and final component of Earth system law: planetary justice.

3. Planetary justice

Scientists have stated that the Earth system comprises three spheres which are constantly interacting through, inter alia, pollutants, resource extraction, and

energy/matter/information fluxes: the anthroposphere, the geosphere, and the biosphere (Steffen et al., 2020). However, given unsustainable development within the anthroposphere, and the way it interacts with the other spheres (mainly how it extracts resources and pollutes them), it hinders their ability to maintain their ecological functioning, increasingly leading to the disappearing of the Earth's Holocene-like state (Steffen et al., 2020). Furthermore, such unsustainable development and destabilisation of the Earth's Holocene-like state, have led to several injustices within the anthroposphere. This can be observed with the relationship between increasing global inequalities and the number of victims of climate-related harms (Klinsky and Mavrogianni, 2020).

Here, planetary justice is the conceptual lens looking at the equitable distribution of resources and ecosystem services within the anthroposphere and between the anthroposphere, the geosphere and the biosphere. This concept develops from recognising that the Anthropocene predicament is an issue of injustice: on the one hand, those who have been profiting by destabilising the Earth system, and on the other hand, the victims of living on a planet whose some biogeochemical processes operate in risk conditions (Adelman, 2021; Biermann et al., 2016).

To highlight a planetary injustice, we can look at current problems on food production and security. Food production is enough to eradicate the world's famine, however, the global North controls more than half of the world's food (as northern lifestyles demand food availability regardless most of it is wasted), while most of the world's population and hungriness are concentrated in the South (Vásquez Bustamante, 2015). Furthermore, the global North (plus China) is mainly responsible for climate change, while the global South is the primary victim of climate-related harms, such as extreme droughts, hindering the South's ability to ensure their food security (Kamal Uddin, 2017). So, within the anthroposphere, the food crisis (as an example of a planetary injustice) is observed through the unequal distribution of food and unequal exposure to climate change. In terms of such planetary injustice, but between the Earth's spheres, current food production occupies around 50% of Earth's biocapacity, which, along with the demand for energy, water, construction materials, humanity is exceeding Earth's capacity to maintain its Holocene-like state (Wackernagel et al., 2021). Addressing this issue requires a more equitable distribution of resources and ecosystem services all around the Earth system.

Since justice is a fundamental principle of the rule of law (Rispoli, 2020), this paper suggests that an effective Earth system rule of law requires achieving planetary justice. Research has shown that including beyond the anthroposphere in the scope of justice increases the likelihood of its preservation (Lecuyer *et al.*, 2018).[8] To this extent, by locating the Earth system into the scope of justice, the law, for instance, through legal processes of justice administration, can be an efficient path for protecting Earth's Holocene-like state.

For doing so, planetary justice is embedded in a new global ethic that moves away from an economy uprooted from Earth with runaway production and consumption rhythms to become an economy inserted as a subsystem within the Earth system (Lander, 2011; Lecaros Urzúa, 2013). This new global ethic is based on better distribution of goods within the anthroposphere, and adjusting current development pathways to planetary boundaries (Herreros, 2010). An example of this new global ethic in justice administration is found in the court ruling STC 4360-2018 issued by the Supreme Court of Justice of the Republic of Colombia (2018), which states that we need to limit unsustainable lifestyles characterised by consumerism, resource depletion, pollution, and growth, destroying the environmental conditions needed for human survival. Constraining our economies within the ecology will keep us from crossing planetary thresholds and maintaining Earth's Holocene-like state for future generations (Svampa, 2019; Wackernagel et al., 2021).

As a metaphor, through the lens of planetary justice, Earth system law must ensure that all the gears within the anthroposphere work aligned with the Earth system machinery; otherwise, the whole machine breaks down. For doing so, Earth system law must find support on Earth system science to identify (in consideration of the limitations that this may have, but always with high scientific integrity) the required distribution and allocation of resources and ecosystem services to maintain the Earth's Holocene-like state. Certainly, because scientific and legal standards of proof are different, there will be challenges to the admissibility of

[8] Although this has been explored mainly in the field of Nature's rights, we do not suggest that the Earth system should be acknowledged as a legal person since, as previously stated, the Earth system is an interconnected, complex, adaptive system composed of processes, cycles, and fluxes, which are the very foundations that sustain most existence of earthly beings. As such, we do not envision the Earth system as a subject but rather as the planetary conditions or as a system state on which life exists.

scientific evidence stating ecological needs in justice provisions. This could be the case when arguing about allocating resources to maintain the hydroclimatic and the hydroecological regulation in water planetary sub-boundaries (Gleeson et al., 2020). However, planetary justice recognises that the biosphere and the geosphere (not only the anthroposphere) have a *prima facie* right to be protected, as the Earth is their only viable basis of existence (Baxter, 2005; Garver, 2019). Integrating scientific insights in law enforcement and court ruling is critical for moving towards Earth system law; a practice that has become quite relevant to achieve justice in the context of climate change (Marjanac et al., 2017). Accordingly, the same should be done to achieve planetary justice: leveraging scientific evidence to adjust development pathways within planetary boundaries and identify an equitable distribution of resources and ecosystem services within the Earth system.

4. Bonding the three pillars

Theoretically, the conceptual lenses of adaptiveness, systems regulation and planetary justice hold the promise to be supportive with each other and coexist harmoniously within Earth system law. This is so in the way adaptiveness can enhance systems regulation by adjusting local dynamics, development pathways and legal provisions according to the ecological structures, processes and cycles on which human activities need to fit within. Furthermore, systems regulation can support adaptiveness by limiting the destabilising effects of global dynamics at the local level (e.g., through resource overexploitation to meet trade agreements). That way, systems regulation can avoid conflicts over resource access and environmental depletion, which are features of low societal adaptiveness.

Likewise, planetary justice can support systems regulation by looking at the equitable allocation of resources and ecosystem services within the social and between the social and the ecological. Suppose economic interactions (e.g. between remote systems) do not foresee this equitable distribution and lead to crossing ecological constraints. In that case, they should be subjected to processes of justice administration in the light of scientific evidence stating the ecological destabilisation and under the perspective of the new global ethics that underlie planetary justice. Also, planetary justice can serve as a fundamental value of adaptiveness and guide the iterative change processes. This way, local provisions

will have an axiological base and justification for enhancing adaptiveness to protect the Earth's Holocene-like state. Nonetheless, theoretically, these conceptual lenses have mutual supportiveness; there is a need to discuss the potential of these conceptual lenses to better integrate Earth system science into the law for moving towards a new notion of Earth system law.

IV. Discussion

Earth system scientists argue that current scientific discoveries must integrate broader tools, policy ideas and innovative research in the social sciences to address issues within the anthroposphere (e.g. injustices) while improving our understanding for maintaining the Earth's Holocene-like state (Steffen et al., 2020). However, this is a two-way path since embracing the complex-adaptive nature of the Earth system in human-devised institutions (such as the law) for better navigating the Anthropocene requires the support of natural sciences (Lopez Porras, 2021b). As previously discussed, the conceptual lenses of adaptiveness, systems regulation and planetary justice can facilitate the transition towards a new legal paradigm that embraces such perspective: Earth system law. While this discussion explores the implications of doing so, it also discusses how these can potentially integrate Earth system science to better address the challenges posed by the Anthropocene.

First, Earth system law must fully embrace adaptiveness. This is about establishing formal sources of adaptation so that the law can better adapt to and guides human activities according to Earth system dynamics while enabling and facilitating the societal ability to adapt to ecological change. Doing so requires moving from static and rigid provisions to more flexible, iterative, subsidiary and connective laws that enable management and decision-making at the most suitable scale. Nevertheless, as each complex adaptive system has its unique dynamics and faces its particular challenges, the legal and institutional principles of adaptiveness are drawn from the understanding that adaptiveness will be context-dependent, and this will be how it will be integrated into the law. It is not in the scope of this paper to discuss the social and political components required to drive such institutional change and to what extent they should be prepared to embrace adaptiveness. However, it is necessary to explore how adaptiveness should look like in the law.

Lopez Porras *et al.* (2019) identify how the Mexican water law can enable adaptiveness through the establishment and actions of Watershed Committees, which are collegiate organisations with government and private participation, for designing rules and managing water at the watershed scale. The result consists of laws and policies that allow the continuous verification and restructuring of their provisions according to environmental uncertainty and non-linearity (iterative and flexible), with locally suitable environmental standards (subsidiarity), that create public spaces for participation and collaboration (connectivity), and which provide legally binding authority and the necessary resources to local decision-makers for avoiding the red tape that hinders adaptiveness (Lopez Porras et al., 2019). Furthermore, Hill Clarvis et al., (2014) state that given the greater flexibility inherent to secondary legislation, it has excellent potential to embrace and enable the adaptiveness principles. Mandatory administrative requirements on monitoring and reviewing standards for adjusting them according to local socio-ecological dynamics (e.g., resource availability and climate variability), with clear deadlines and reporting mechanisms for ensuring legal iteration, subsidiarity, and flexibility are examples of how secondary legislation can enable adaptiveness (Hill Clarvis et al., 2014). Further examples of adaptiveness are found in Puerto Cortés, Honduras, where state and non-state actors collaborate to adjust local standards and provisions according to local environmental priorities (societal adaptiveness (Domínguez Serrano, 2011)), and on Ruhl's, (2011) proposal on adaptive climate change adaptation law (institutional adaptiveness).

On this point, iteration and flexibility play a significant role in linking science to Earth system law. Research shows that monitoring (e.g. quantifying the ecological consequences of management decisions), retrospective analyses (e.g. examining policy and legal effectiveness to maintain ecological stability), and scientific-based guidelines/standards (e.g. water quality guidelines) are important activities for collaborating at the law–science interface (Moore et al., 2018). Indeed, these actions are supportive of the achievement of iteration and flexibility by providing ecological data to adjust policies and standards. For example, on revising if water-related legal provisions meet water planetary sub-boundary requirements to maintain soil moisture and streamflow at the local or regional level (Gleeson et al., 2020). However, we must be aware that integrating science into the legal arena

is a challenging task. Scientists must effectively inform about the limitations and strengths of existing evidence in identifying ecological processes and cycles, along with their thresholds, as they may not exist for some species or processes (Moore et al., 2018). Additionally, when aiming to enable adaptiveness, here are some critical questions regarding the challenges that will potentially arise in terms of governance and linking science and the law, whose responses, which are context-dependent, will help guide this process: What are the acceptable levels of ecological risk on which regulatory standards must be drawn? What actions (e.g. monitoring or retrospective analyses) better fit to link science and the law? Are there any conflictive perceptions/ interests that may hinder collaboration? What would be the cost of scientific data? Are there enough resources for having access to it?

Adaptive laws that accord with their socio-ecological context are also better accepted and supported by civil society, giving rise to better compliance and easier enforcement (Leitao, 2016; Lopez Porras et al., 2020b; Pejovich, 1999), ultimately strengthening an Earth system rule of law. That is why (as the examples provided from Mexico and Honduras) adaptiveness must emerge from these lower-level interactions that play a significant role in the socio-ecological interplay, ultimately shaping the Earth system (Levin et al., 2013; Lopez Porras et al., 2020b). As stated in the examples above, secondary legislation and local organisations endowed with formality and autonomy to design and implement legally binding provisions are critical for a new notion of Earth system law to integrate adaptiveness.

As far as system regulation is concerned, the telecoupling framework could be a valuable tool for analysing the destabilising effects that cross-level and cross-scale interactions have. Even if such interactions are not between remote systems but still identifiable in their causes, agents, flows and effects. Better identifying such destabilising effects increases the law's potential to provide the required prescriptions for fitting human dynamics within the ecology. As an illustration, trade and investment agreements on which many telecouplings are legally founded could integrate legal provisions on revising the feedback effects that such trades and investments can have on the Earth system processes (e.g., evapotranspiration and carbon uptake (Du Toit et al., 2021)). Likewise, this notion of systems regulation should be integrated into domestic environmental legislation, especially in countries whose economies mainly rely on exploiting and exporting their natural resources.

If telecouplings' effects are not foreseen and regulated, genuine sustainability and environmental protection will be hard to achieve.

On top of that, to identify the ecological structures, processes and cycles on which human dynamics need to fit within, Earth system law can rely on Earth system science to consider non-linear dynamics and spatial patterns—enabling the regulation of human interactions with the cycles, fluxes, and processes that make up the Earth system. For instance, machine learning approaches can predict fire occurrence and spread, phenological phases of vegetation, and seasonal variation of carbon dioxide fluxes (Reichstein *et al.*, 2019). In this sense, to protect Earth system, machine learning predictions of Earth system processes can highlight how destabilising development programmes or extractive activities would be, to design and enforce the required regulations. Likewise, Earth system models (e.g. CNRM-ESM 2-1 (Jones, 2020)) can assess future projections and changes in Earth system components to inform required legal actions to protect the relatively stable planetary conditions in which the Earth system should operate.

Notwithstanding, this does not mean that scientists will start rewriting environmental legislation. However, Earth system science data will provide empirical evidence on which lawmakers can base, along with other values (e.g., health, social, cultural, economic) the regulatory prescriptions to meet collective needs of ecological protection, specifically, to maintain the Holocene-like state. In summary, systems regulation aims to provide the conceptual basis, so Earth system law can design legal provisions and regulations that are able to limit human dynamics according to Earth's capacity to maintain its safe operating conditions. For doing so, it should be able to integrate Earth system scientific insights.

Finally, in an Earth system law context, justice should be provisioned to balance current inequalities within the anthroposphere, and ensure an equitable distribution of resources and ecosystem services among the Earth system spheres. Accordingly, enabling the planetary justice discussed in section 3.3 requires at least working on three aspects when discussing, portraying, and provisioning justice.

Firstly, as part of the required new global ethic, we need to eradicate wrongful assumptions and notions of justice. For example, those based on the idea that

unlimited economic growth and trickle-down (money coming from the North in exchange for the South's goods and labour) are the answer to global inequalities; conversely, current socioeconomic dynamics are increasing global inequalities and leading to the cross of planetary boundaries (Guimarães, 2012; Heinze, 2020; Spash, 2020; Wackernagel et al., 2021). Secondly, enabling planetary justice also requires integrating the *cosmovisions* and knowledge from the global South, especially those not written in English. For instance, Spanish-written literature, environmental activism, and court rulings produced in Latin America acknowledge that setting ecological constraints and planetary boundaries to unsustainable lifestyles (most of them taking place in the global North) is the only way to address inequalities within the anthroposphere (Alvarado et al., 2018; Estenssoro Saavedra and Vásquez Bustamante, 2017; Mexican Supreme Court of Justice, 2018a; Supreme Court of Justice of the Republic of Colombia, 2018; Svampa, 2019). Yet, English-written literature discussing the same topic does not acknowledge the above (Biermann and Kim, 2020; Saunders, 2015). Thirdly, planetary justice within Earth system law needs to guide the establishment of a model of society favouring "the interest of the ecosystem above the individual interest of its components, but eventually in accordance with the overall communal interest" (Bologna and Aquino, 2020, p.7). Although this seems radical and hard to imagine, courts are moving in that direction.[9] For instance, in a lawsuit against the Colombian government for failing to protect the Colombian Amazon and prevent deforestation, the Supreme Court of Justice of the Republic of Colombia, (2018) ruled that the intrinsic value of nature "transcends the anthropocentric perspective, and focuses on 'ecocentric-anthropic' criteria, which places the human being on par with the environmental ecosystem".[10] Supporting this, there is a jurisprudential thesis[11] issued by the Mexican Supreme Court of Justice, (2018), stating that the nucleus of the human right to a healthy environment goes beyond humanity's most immediate objectives, so adequate protection of the environment requires protecting nature for its intrinsic

[9] See for example Juliana v. United States, No. 6:15-CV-01517-TC, 2016 WL 6661146 (D. Or. Nov. 10, 2016), Urgenda Foundation v. Kingdom of the Netherlands, [2015] HAZA C/09/00456689, and Leghari v. Republic of Pakistan (2015) W.P. No. 25501/2015.

[10] Author's own translation.

[11] Jurisprudential thesis refers to the legal doctrine that reflects the Supreme Court's criteria and reasoning on interpreting and applying the law. The lower-level courts are constrained to judge according to such legal doctrine (Serna de la Garza, 2009).

value. Accordingly, the human right to a healthy environment also has an objective or ecological dimension, which means that regardless of its interdependence and positive effect on other human rights, such as health, life or personal integrity, it acknowledges the environment's intrinsic value and importance for other living organisms with whom we share the planet, locating them within the scope of such human right (Mexican Supreme Court of Justice, 2018).

Moreover, Earth system law must integrate Earth system science to ensure an equitable distribution of resources and ecosystem services among the anthroposphere, biosphere and geosphere. For example, in Colombia's tropical ecosystems, Estupinan-Suarez et al., (2021) identified land-surface processes related to climatic and land-use drivers for determining environmental conditions for biodiversity. In doing so, the authors unravelled ecosystem dynamics and functions, which would improve their management in terms of seasonal variability, ultimately enlightening ecosystem needs in terms of their structures and conditions (Estupinan-Suarez et al., 2021). In terms of planetary justice, this could identify the resources and ecosystem services that ecological systems need to ensure they are not deprived of them and maintain their stability.

When planetary injustices occur, Earth system science must facilitate the achievement of planetary justice. For example, accomplishments in other fields of law, such as climate law, can provide useful insights into how planetary justice can be obtained in an Earth system law context. For instance, Marjanac *et al*. (2017) explain how, through the integration of attribution science and climate litigation, it is possible to establish liabilities when governments and corporate directors fail to act regarding foreseeable climate-related risks. Similarly, we should explore advances within Earth system science. In particular, a new notion of legal practice under the idea of Earth system law (Earth system litigation) can integrate the aforementioned machine learning approaches to map human-induced destabilisation of Earth system processes. This has the potential to provide scientific evidence that establishes liabilities and hold accountable those negatively impacting the Earth's Holocene-like state, thus achieving planetary justice and enabling an effective Earth system rule of law.

V. Conclusions

We now understand that the most outstanding asset of the Earth consists of its life-enabling conditions provided by the interacting suit of natural cycles, biogeochemical processes, and energy fluxes. Therefore, avoiding their destabilisation should be a collective interest and a global priority. Although there are now some scientific endeavours to explore legal and institutional responses to protect the well-functioning state of the Earth system, there is still much left to do in achieving a new legal paradigm that fits such requirements. In this sense, this paper proposes a conceptual framework that aims to cover some essential aspects for achieving that new legal paradigm, which has been called "Earth system law".

Adaptiveness, systems regulation, and planetary justice are the core elements of this conceptual framework that can transform the law into a social construct suitable for addressing the regulatory challenges posed by the Anthropocene, and this paper provides valuable insights on how the law can embrace them. By doing it, we will be able to move towards Earth system law, a new legal paradigm able to contain the human enterprise within planetary boundaries and protect the cycles, processes, and fluxes that maintain the Earth in a well-functioning state.

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