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OPINION PAPER

Instructions for a Sustainable Anthropocene

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Abstract
Is it possible to achieve a sustainable Anthropocene? Yes, if we adopt the correct key for understanding the mechanisms that connect the three dimensions of sustainability, the environmental, the social and the economic. The road to sustainability is made even harder than it was at the beginning of the sustainable development discourse by the fact that nowadays the three dimensions have problems that have time spans that tend to become equally urgent. This paper offers a vision of sustainability that underlines the cause-effect-feedback relationships among the dimensions and shows examples of the functioning of these linkages. This calls for a redefinition of priorities and for a different set of "rules of the house" (economy) to be fit for a world with almost 8 billion people and an endangered natural basis of survival.

Keywords The Anthropocene · Cause-effect-feedback · Sustainable development · Sustainability

1 Introduction

The Anthropocene can be generally defined as a new epoch in which human effects dominate many of the Earth's cycles (Frank et al. 2022). Examples of that are the alteration of the Earth's climate by human activities (Barnosky et al. 2012), and the evidence that more than 50% of the Earth's land surface area has been altered for human uses (Hooke and Martín-Duque 2012). This new epoch thus seems to point to an imbalance between the three elements of sustainability, i.e., the environment, the economy, and society, with the latter two overcoming in scale the former, thus hampering the realisation of sustainable development. Today, 35 years have passed since Brundtland's report, and sustainable development is still far from becoming an actual lifestyle for humanity. There have been political-social-economic conditions that have prevented the realisation of this goal, but we have also to analyse if something was present, in the narrative of sustainable development, that slowed down the comprehension and application of the concept.

Since the beginning, sustainable development has been viewed as a process of interaction among "the biological and resource systems, the economic system, and the social system" (Barbier 1987). The common representation of sustainability consists of three intersecting circles of these elements. The area of intersection of the three circles is where sustainable development occurs (Fig. 1). This representation is in line with the idea that sustainability must consider the goals of economic and social activity, together with environmental protection. However, in its applications, it has shown three main weaknesses: (i) it is a static representation that does not include the temporal dimension of sustainability as intended by the Brundtland Commission; (ii) it allows us to think that, if there are good indicators of economic performance, social status, and environmental protection, the system is sustainable: Regardless of the fact that these indicators have generally improved for most countries, we cannot say that overall sustainable development has progressed since 1987; (iii) except in the central area where all sustainability requirements are met (very difficult to achieve), it implies that the environmental, social, and economic components of

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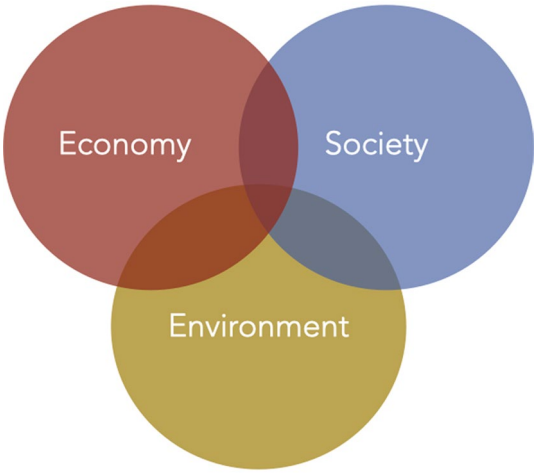

Fig. 1 The "usual" representation of sustainability (Barbier 1987). Sustainability is attained only at the intersection of the three spheres

sustainability are somehow interchangeable or substitutable. This substitutability of environmental, social, and economic elements has been often called "weak" sustainability (Pearce and Atkinson 1993; Gutés 1996) and it has proven unable to address the problems and the limiting factors arising. This is due to the fact that sustainability, in this view, is seen as a trade-off among the environmental, social, and economic aspects. This condition means that, outside the central area, we are allowed to accept better economic conditions at the expense of quotas for social and environmental health (or other similar combinations).

Furthermore, the temporal scale on which the three elements of sustainability function has always been perceived as different: the economy is working in short terms, society in mid-terms; and the environment in long terms. Therefore, policies, even those referring to sustainable development, have naturally tended to preserve "business as usual", first of all by pushing the growth of the economic system to reap short-term rewards, hoping that society would benefit from it and, secondly, that the environment would not be harmed too much. As a result, the pursuit of an economic result—preferably its maximization—is always prioritised because it is regarded as necessary for achieving social stability and environmental protection. Unfortunately, this is not the case, as it has been shown many times: see, for example, the emergence of social disease in the case of inequality in different countries independently of income levels (Wilkinson and Pickett 2009). In addition to that, while the economy remains a central policy priority in the Anthropocene, the discipline of economics encompasses fundamental disagreements (Coscieme et al. 2019). This is in contrast with, for example, environmental disciplines, such as climatology, characterised by widespread agreement on their fundamental theory and a much better track record in terms of predictions and explanation of underlying mechanisms (Dietz et al. 2007; Turner 2014; Herrington 2021).

Nowadays, the times of the environment have shortened and are increasingly unpredictable, many Earth systems are in the zone of uncertainty and some are beyond the threshold (Rockström et al. 2009a, b; Steffen et al. 2015; Lade et al. 2020); on top of that, the ongoing climate change leads the planet too far from thermodynamic equilibrium (Kleidon 2012). The consequences are chaotic dynamics of processes in many earth systems, with short and variable times and unpredictable evolution, which are already in place and affecting millions of people worldwide (particularly the most vulnerable).In this way, environmental, social, and economic problems have become equally urgent and there is no space for compromise: sustainable development is achieved only if the environment, society, and economy are respected altogether and at the same time, as stated in the UN Agenda 2030 (United Nations 2015).

2 Sustainability in the Anthropocene: A Dynamic and Consequential Approach

The Anthropocene does not have to be necessarily unsustainable. A "good" Anthropocene "in which human quality of life may be maintained or improved without cost to the environment" (Jeanson et al. 2019) is attainable by learning from and implementing trans-disciplinary and collaborative approaches that embrace multiple worldviews into decision-making (Coscieme et al. 2020). Ultimately, a good Anthropocene is based on principles and actions that recognise that biodiversity and healthy ecosystems are requisite for sustained human life.

In this vein, we developed a more logical/consequential approach for the representation of sustainability that recognises the dependency of the economy on societal organisation, environmental resources, and ecosystem services (Pulselli et al. 2015). This framework for the environment, society, and economy can help highlight the connections between them and provide guidance on how to make even the Anthropocene sustainable.

Our approach starts with a three-storey pyramid representing relationships between the three dimensions of sustainability. At the base of the pyramid are natural assets, which must be solid and stable and provide crucial inputs to the system, including the energy and matter that feed society and economic activity. The intermediate level is what we really care about: our society with its organisations and structures. The top level of the pyramid (or the tip of the iceberg, to use another image) is the real economy that represents the "useful" output of the system (Fig. 2). This picture can be considered an evolution of the three concentric circles representation, also used to combine environmental, social,

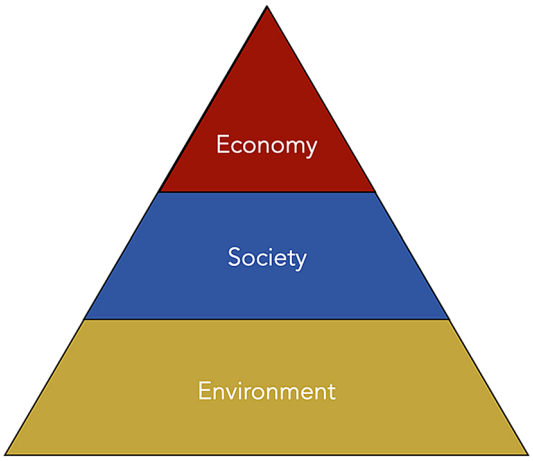

Fig. 2 A "functional" representation of sustainability. The environment is at the base of sustainability, with its necessary conditions (see Daly 1990); society is at the centre of our attention, what we aim to satisfy in its needs and well-being; the economy is the "tip of the iceberg" as it emerges from society

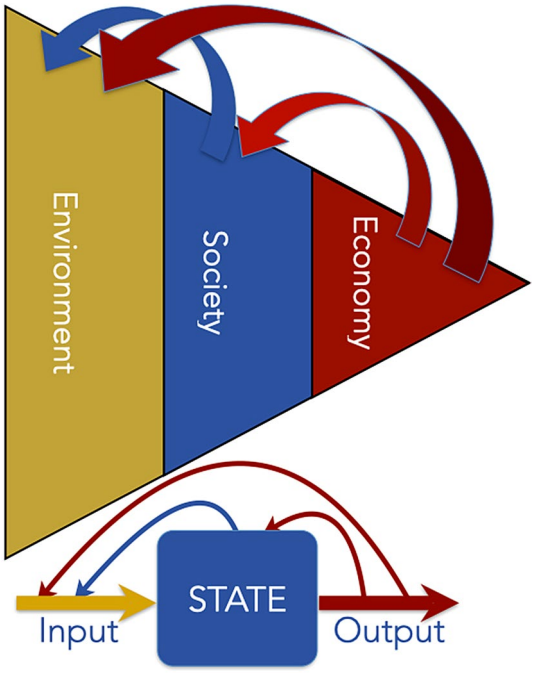

Fig. 3 A "cause-effect" representation of sustainability. The environment provides goods and services to society; society creates an economy; the economy provides feedback to society and the environment; and society provides feedback to the environment

and economic components (Lozano 2008). While the latter shows purely physical embedding, the pyramid suggests logical dependency: which components support which.

Let us now rotate the pyramid clockwise and orient the succession of stages (from left to right): a flow of material and energy inputs, generated by the available stock of natural assets, feeds (or is captured by) the system. These resources are necessary for the elements of the system (namely, society and its organisational units) to operate (act, live, survive, develop, and evolve); the level of organisation of society influences the degree of utility/satisfaction derived from processing/using/consuming resources. An organised society should be able to achieve better economic results through the output of its production processes.

By rotating the environment-society-economics pyramid, we have translated a static view into a dynamic input-state-output representation (Fig. 3). This logical structure shows how the three dimensions work together through cause-effect relations, interactions, and feedback (represented in Fig. 3 by arrows going backwards). The environment is the "material cause" (input) for society and with its limits, humans have to deal with if they want to prosper. As for all living systems, necessary and less necessary consumptions for humans derive from the environment. A society (state) is in prosperity if it succeeds in using in the best possible way the inputs of various kinds that derive from the environment; it organises so as not to leave any of its members behind; and it generates an economy (output) that co-produces and distributes the goods and services needed by the society itself. Qualitatively, feedback between the environment, society, and the economy can be positive (thus contributing to the whole system's health and development), or negative (thus destabilising the system and potentially disrupting its development):

(a) *Feedback from the economy to society:* These are, for example, the incomes of workers, the taxes paid so that society can provide education, health, etc. to its members, but also the negative consequences of excessive workloads or deteriorating working conditions to keep up with the economic cycles.
(b) *Feedback from the economy to the environment:* These are nowadays almost always negative feedbacks, such as emissions of pollutants, wastes, etc. from economic activities. Just a few of these are positive feedbacks, for instance when some residues of agriculture are re-inserted into the environment, or in general when the economy "invests" in natural assets, thus contributing to the compensation of the unavoidable impacts due to production systems.
(c) *Feedback from society to the environment:* Also, these can be both positive and negative. Negative examples include the production of household waste, pollution from the use of fuels for transportation and heating, and, more broadly, a lack of education (a social weakness) that implies apathy in addressing environmental issues and progressive damage, such as the proliferation of plastics in oceans, among others. On the posi-

tive side, we can have policies for the protection of the environment or biodiversity, and voluntary activities that involve planting trees, restoration of polluted areas, etc.

3 Evidence of the Input-State-Output Relationships

The COVID-19 pandemic has practically shown the dynamics between causes and effects in the environment-society-economy (input-state-output) relationship: a wrong use by humans of the environment (deforestation, habitat and biodiversity loss, and large livestock farming, aggravated by pollution) has triggered a real environmental crisis (IPBES 2020; Harvard Chan C-CHANGE 2019). The environmental crisis quickly became a social crisis because the pandemic spread everywhere and caused the need for lockdowns since being "social" became a problem. This caused the economic crisis: without a functioning society, production became impossible.

Our interpretation of sustainability in terms of cause-and-effect relationships (and feedback) is able to discern such a chain of events. The World Economic Forum publishes the Global Risk Report every year. The 2021 edition, in line with that of 2020, shows that extreme weather, climate action failure, human environmental damage, biodiversity loss, and natural resource crises are perceived to be in the top 10 major risks for humanity by both likelihood and impact, overcoming the importance of infectious diseases, debt crises, digital inequality, and interstate relations fracture (WEF 2021). The ongoing war in Ukraine shows the same dynamics since the shortage of gas and the excessive reliance on trade for some key commodities are causing problems for the social systems of the world and can have a big impact on inflation.

Therefore, thinking of doing politics focusing first of all on economic performance, trusting or hoping that the feedback on society would be positive and on the environment not too negative, is turning out to be a hoax. It was probably a model that could fit into an "empty world", in which the environment could be considered abundant and substantially unchangeable by human actions. The fact that this model no longer adhered to the reality of the facts began to emerge after Rachel Carson (1962), the Limits to Growth study (Meadows et al. 1972), and others raised awareness of the fact that we, humans, were radically changing the environment that hosts and feeds us. In the Anthropocene, the environment cannot be assumed to be infinite and unchangeable, a hypothesis (explicitly or implicitly) at the heart of most economic theories.

4 What We Learn: Instructions for Living in the Anthropocene

At a time when the environmental and social aspects have become equally urgent and with very rapid and equal response times in all three spheres, it is even more important to understand the mechanisms that can lead us out of contradictions and into a more livable world. Climate change, COVID19, biodiversity loss, as well as the WEF report, indicate that our model is valid and should be used to plan the development strategies and policy agendas of human systems at all scales. It is a model that does not envisage seeking compromises between good economic performance, good social cohesion, and a simple "clean"environment. It encourages the simultaneous management of the environmental, social, and economic aspects as a whole, with a legislative system that recognises this whole and regulates human actions both towards the economy and towards the environment, to be recognised as an integral part of the human support system (see, for example, Magalhes et al. 2016).

In this model, there is no room for feedback that is harmful: what comes "back" from the economy and from society must be an overall additional nourishment for the environment, reinforcement, not "pollution". The example of plastic in this sense is striking and, despite the fact that scientists have reported this phenomenon for decades, today those who eat fish also eat plastic. When we drink water, we nowadays ingest micro-plastics, when we eat meat or vegetables, we often eat pesticides and/or other pollutants: the negative feedbacks that reach the environment goes back to our society and endanger our health and that of future generations (see, for example, Ragusa et al. 2021) and, ultimately, our economy.

A view of the system as a whole and related problems calls for adequate tools and frameworks, such as the Input-State-Output described here. Other sets of tools, suitable for improving knowledge, identifying problems and finding solutions on a global scale, can be found and adopted. Two groundbreaking recent approaches are the 17 Sustainable Development Goals promoted by the UN Agenda 2030, approved in 2015, and the Planetary Boundaries framework (Rockström et al. 2009a, b; Steffen et al. 2015). These sustainability pillars are in line and mutually related with the I-S-O framework, and may help identify solutions for flourishing within limits to growth (Jørgensen et al. 2015). The key point for Sustainable Development Goals is that they must apply to everyone; no one should be left behind; and must be met as a whole, not favouring some goals over others, because they must overcome the business as usual situation, in which they could be seen as in opposition to each other (the SDG framework's

"universal", "integrative", and "transformative" principles). The Planetary Boundaries framework, on the other hand, shows how risky the situation can become with respect to the natural cycles and environmental assets disrupted during the Anthropocene.

Our model indicates a precise path of development, which is also a path of human and technological development. We must be able to intercept and use what the environment gives us in a renewable and responsible way to power all societies in the world. The economy should go back to its original role: set up the "rules of the house" (*oikos* and *nomos* in ancient Greek). The economy is the instrument that we, as a human society, use to pursue our welfare, well-being, or even happiness in the presence of scarce resources. Economists should find the right way to achieve this target. For decades, or even centuries, we have mixed up the instruments with the aim. But this was conceivable in the empty world, not in the Anthropocene: when environmental quality and resources become limiting factors for a prospering society, the economy has to redefine itself to be able to lead us outside the contradiction between growth and well-being. The rules of a "house" with less than a billion people (the "empty world" of when most of the economic theories were established) cannot be the same as the ones with 8–10 times more people inside and with the natural basis of our survival so in danger.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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