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ORIGINAL ARTICLE

Thou shalt not take the name of bioeconomy in vain

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Abstract
In this paper, we show that the characteristics of complex adaptive systems support the original interpretation of the bioeconomy of Georgescu-Roegen: the current use of natural resources by industrialized societies is incompatible with the regeneration processes of ecological systems. Elaborating the concept of societal identity, using a biosemiotics reading of the social theory of Luhmann, we show that the current social identity is sustained by implausible sociotechnical imaginaries, including the European Union's interpretation of the bioeconomy as a panacea for green growth. We argue that the current widespread perception of polycrisis is a sign that, on the tangible side of biosemiotic process, social practices urgently need change. On the notional side, however, society is (still) incapable of relinquishing the set of sociotechnical imaginaries grounded in the American and Cartesian dreams (the promethean ideology) firmly locked in its collective memory. This incongruity has produced information disorder in the sustainability discourse. We conclude that the EU endorsement of the concept of the circular (bio)economy as a strategy for perpetual economic growth decoupled from resource use represents a desperate attempt to maintain the status quo through the endorsement of an integrated set of noble lies.

Keywords Complex adaptive system · Social identity · Sociotechnical imaginary · Uncomfortable knowledge · Noble lie · Toxic truth

Introduction

The bioeconomy has been increasingly put forward by national governments and pan-national organizations as a panacea to sustain economic growth in the face of rapidly growing sustainability challenges (e.g., Dietz et al. 2018; European Commission Directorate-General for Research and Innovation 2018; BMBF and BMEL 2020; OECD 2009; The Norwegian Government 2016). Many policymakers and scientists alike seem to be unaware that the concept of bioeconomy was introduced in the sustainability discourse more than a century ago, with exactly the opposite message, i.e., the need to carefully consider and acknowledge the implications of external constraints and limits imposed by nature on economic growth (Georgescu-Roegen 1971, 1977; Gordon 1954; Mayumi 2001). According to Eversberg et al. (2023a, b), Proestou et al. (2024), and Vivien et al. (2019), ever since the concept of bioeconomy was coined, it has been used to serve diverse political agendas by attributing different meanings to it in policy discourses.

The term was first introduced in 1918 by Russian ecologist Fedor Baranov in his paper "On the question of the biological basis of fisheries". Based on his profound knowledge of fish population dynamics, he suggested that the fishing sector (a primary economic sector) should be based on a preliminary understanding of how many fish can be caught and how. "Baranov referred to his work as 'bionomics' or 'bioeconomics' although he made little explicit reference to economic factors" (Gordon 1954, p. 125). His work hardly received any attention in the West, due to it having been published in Russian and its rather technical nature, and never entered in the sustainability discussion. As a result, the idea of 'bioeconomics' remained dormant until the 1970s, when the Romanian economist Georgescu-Roegen published "Energy and Economic Myths" (Georgescu-Roegen 1975)

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and "Bioeconomics: a new look at the nature of economic activity" (Georgescu-Roegen 1977). Georgescu-Roegen's use of the concept bioeconomics represented an urgent call for a new form of economic analysis capable of addressing the implications of the biophysical roots of the economic process and the incompatibility between the use of natural resources by industrialized societies and the regeneration processes of ecological systems (i.e., the lack of sustainability) already emerging at his time (Mayumi 2001). Thus, in its original interpretation, *bioeconomy*—i.e., the interaction of the economic process with the embedding ecosystems—required a new discipline, *bioeconomics*, complementing conventional economics, to provide a holistic view of the factors determining sustainability (Gowdy and Mesner 1998; Mayumi 2001).

The second interpretation of the term bioeconomy surfaced during the late nineties and was about a strategy of technical innovation based on the imitation of biological and ecological processes (i.e., biomimicry or nature-inspired innovation) (Vivien et al. 2019). This interpretation supports the belief that major improvements in the efficiency and sustainability of the economic process can be achieved by technological innovations using "nature as a mentor". Also called the knowledge-based bioeconomy, it was expected to facilitate the development of "a bio-based economy powered by industrial biotechnology, which was essential to deliver on post-Paris (COP 21) climate commitments, reducing greenhouse gas emissions and the dependence on fossil resources" (Patermann and Aguilar 2018). In this interpretation, bioeconomy is a mere promise made by the biotechnology industry and associated lobbies.

The third and most recent interpretation of bioeconomy, often associated with the idea of a circular economy, is about moving to a bio-based carbon economy that is assumed to solve, simultaneously, the problem of exhaustion of fossil energy sources and the problem of excessive GHG emissions (Giampietro 2019; Vivien et al. 2019). In this vision, economic growth is decoupled from natural resource consumption and, hence, avoids addressing the limits to growth (EEA and Eionet 2022). This third interpretation also builds on the assumed potential of technical innovations and new business models inspired in natural processes to solve our sustainability problems, but this nature-inspired strategy is now expected to amplify the entire economic process, thus representing a pseudoscientific endorsement of the idea of perpetual economic growth (Giampietro and Funtowicz 2020). This interpretation is currently used as a basis for policy making in the European Union (EU) (European Commission Directorate-General for Research and Innovation 2018, 2022).

While the original interpretation of the term bioeconomy focuses on the need for a new scientific discipline providing a theoretical basis to study the implications of the impossibility of the perpetual economic growth of post-industrial societies, the second and third interpretations are based on the belief that the mimicry of natural processes can dramatically improve our capability of producing and consuming economic goods and services while, at the same time, reducing the environmental impact.

This paper reflects on the possible drivers of this evolution of the term bioeconomy, from a critique of the neo-classical economic growth paradigm to an endorsement of perpetual economic growth, and on the resulting information disorder in the sustainability discourse. With information disorder, we refer here to the coexistent misinformation, disinformation and malinformation about the bioeconomy, which currently makes it difficult to generate fair and informed policy discussions. This reflection is important because, as we will argue, the transformation of the meaning assigned to the term bioeconomy currently impairs the practical functioning of the democratic process, notably in the EU. Several other authors have critically examined the different meanings of the term bioeconomy (e.g., Eckert 2021; Eversberg et al. 2023a, b; Kirchherr et al. 2017; Luhmann 2020; Petersen and Krisjansen 2015; Ramcilovic-Suominen and Pülzl 2018; Vogelpohl and Töller 2021) or reviewed the literature on this topic (e.g., Aguilar et al. 2018; Bugge et al. 2016; Dieken et al. 2021; Hausknost et al. 2017), but, to the best of our knowledge, no one has yet related the evolution of this term to information disorder through an analysis of the communication processes shaping the identity of society.

The text is organized as follows. We first provide theoretical support for the original interpretation of the bioeconomy that it is incompatible with the idea of green growth ("Understanding the functioning of living systems"). We then show, in biophysical terms, that the evolutionary path of human society has moved away rather than toward a bioeconomy ("Rupture of the equilibrium between society and environment: the metabolic rift"). Following, we examine the factors and circumstances that have led many to believe that the idea of "nature as a mentor" endorses the conviction that technologies and business models can fix our sustainability problems. To this purpose, we first elaborate the concept of societal identity, using a biosemiotics reading of the social theory of Luhmann ("The changing societal identity") and then analyze the sociotechnical imaginaries sustaining the current social identity ("Implausible sociotechnical imaginaries?"). Lastly, we elaborate on the information disorder that has resulted from the systemic use of implausible sociotechnical imaginaries, in particular the current interpretation of the bioeconomy concept in the sustainability political discourse ("Information disorder"). The final section provides the conclusion.

Undoubtedly, the paper will present an intellectual challenge to many readers because its content spans both the natural sciences ("Understanding the functioning of living systems" and "Rupture of the equilibrium between society and environment: the metabolic rift") and the social sciences ("The changing societal identity", "Implausible sociotechnical imaginaries?", and "Information disorder"). However, given the complexity of the sustainability problem, and that of the bioeconomy in particular, transdisciplinarity is key to understanding and tackling these issues (Harris et al. 2024).

Understanding the functioning of living systems

In their original interpretation of the bioeconomy, Baranov and Georgescu-Roegen both referred to a sustainable use of natural resources in the economic process. With 'sustainable' they intended a rate of exploitation by society (e.g., rate of extraction by the fishery industry) that is compatible with ecological (natural) regeneration processes (e.g., the supply and sink capacity of aquatic ecosystems). Both argued that, to this purpose, it is essential to study the material coupling between economic and ecological processes. In the case of Georgescu-Roegen, an economist, this idea took the form of a critique of the neo-classical economic theory, which considers the economic process to be independent of natural resources. In this section, we present a completely different approach grounded in the fields of chemistry and ecology to provide further theoretical support for the incompatibility of the pattern of economic growth of contemporary society with ecological processes. More specifically, we set out why the metabolic identity of post-industrial society is incompatible with that of natural ecosystems.

Key to our argument is the concept of group autocatalysis or collectively autocatalytic set first introduced by Kauffman, who used the concept to explain the origin of life (Hordijk 2019; Kauffman 1993). [A similar concept is the hypercycle, originally introduced in chemistry, which refers to a special form of organization emerging in chemical reactions (Eigen 1971; Eigen and Schuster 1977, 1978)]. The concept has been applied in theoretical ecology to study the mechanisms of formation of structural and functional relations in complex adaptive systems. Examples are eMergy analysis of the functional structure of ecosystems developed by the Odum brothers (Odum 1971a, b), ascendency analysis developed and used by Ulanowicz (1986, 1997) to study the difference between growth and development in ecosystems, and metabolism–repair relational network proposed by Rosen (1958, 1959, 1977, 1978, 1985, 2005, 2012) and further developed by Louie (2009, 2013, 2017).

In these narratives, living systems—which are complex adaptive systems—are described as metabolic systems operating over different hierarchical levels, in which structural elements (parts) generate a series of functional types (expressing part–whole relations) that, in a synergic collaboration, reproduce the structural elements of the whole (e.g., Lomas and Giampietro 2017; Odum 1971a; Ulanowicz 1986). This postulate is illustrated for a basic ecosystem in Fig. 1, using the iconic graph proposed by Odum (1983).

The left-hand graph of Fig. 1 shows the relations between the functional elements (the nodes)—plants, herbivores, carnivores—of an ecosystem (the whole). The right-hand graph of Fig. 1 details the specific relations among the structural elements (individual organisms) inside the functional node "herbivores". The latter graph shows that the metabolic characteristics of the network can be represented in two non-equivalent ways:

1. From the outside of the node (left-hand graph), i.e., seen from the perspective of the rest of the network, considering the node "herbivores" as a functional whole. This representation defines what the rest of the network expects from this node. This notional identity is stored in the set of established relations (mutual information) in the network.
2. From the inside of the node (right-hand graph), by looking at the metabolic characteristics of the various structural elements operating within the node (each element having its own structural identity). In this way, we observe the tangible aspects of the structural elements of the node (its lower-level parts), whose metabolic identity is determined by encoded information (genome) defining their material organization. For instance, in Fig. 1, this refers to the specific identity of the organisms belonging to the different species operating in the node herbivores, such as sheep, rabbits, and donkeys.

These two different ways of representing functional nodes imply the simultaneous presence of two contrasting directions of causality in the definition of the identity of the metabolic network: a downward causation (what is expected from the functional nodes by the whole) and an upward causation (what can be done and is done given the set of structural elements of the nodes and their characteristics) (Campbell 1974). The two causations are connected in an impredicative relation [see also the similar concept of dialectic biology (Levins and Lewontin 1985)]. For example, the functional node herbivores (made up of structural elements, i.e., a mix of species of herbivores) is expected to consume a set of inputs provided by its context and to provide a set of outputs required by its context.

Hence, to reproduce and adapt this complex organization, ecosystems (and all other complex adaptive systems) must simultaneously express two distinct features:

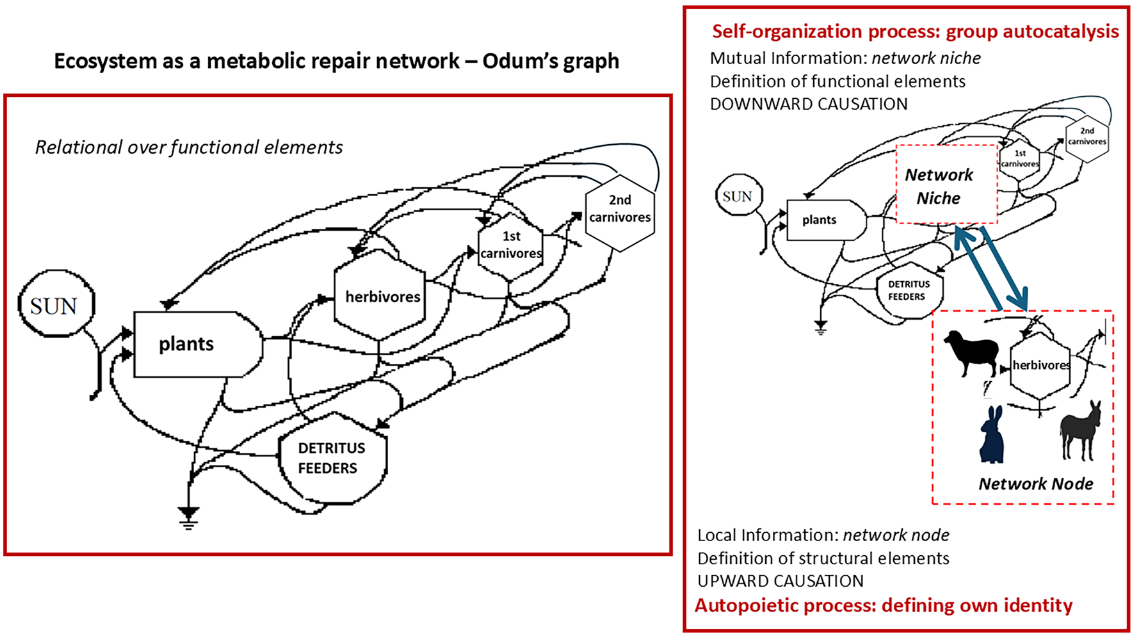

Fig. 1 The complexity of impredicative relations in ecosystems between functional nodes of the whole (downward causation—left-hand graph), and between functional and structural elements within the nodes (upward causation—right-hand graph) [adapted from (Odum 1983)]

1. Self-referential autopoiesis (upward causation): The process by which the structural elements of the node reproduce their own identity associated with the expected metabolic characteristics (e.g., the size of the population of organisms, the rate and density of consumption of inputs and production of outputs). For example, within the node herbivores, rabbits must reproduce into rabbits, sheep into sheep, and donkeys into donkeys. Otherwise, it would be impossible to regulate their mix to establish the congruence between the upward and downward causation.
2. Structural coupling associated with the process of self-organization of the whole network across its various levels (downward causation): This coupling entails the ability of the whole network to obtain the inputs for its overall metabolism from its context. At the same time, each node/niche must supply through their links to the rest of the network the specific inputs required by the other nodes/niches. This means that the outputs of individual elements, e.g., the activity of herbivores, represent inputs to themselves (supporting the processes that are generating them) and, at the same time, to the other functional elements operating in the metabolic network (group autocatalysis in a collectively autocatalytic set).

This complex organization means that the identity of a complex system and its components is determined by an *impredicative* set of relations: the downward causation associated with structural coupling (the expected organization of the whole) does affect and is affected by the upward causation associated with autopoiesis (what can be realized by the processes taking place inside the parts). This impredicativity escapes the conventional approach of reductionist analysis because there are no linear directions of causality in the set of observed relations. Indeed, we are dealing here with a cascade of chicken-and-egg relations: everything depends on everything else.

Another important observation about these complex systems is that the definition of the output of a functional element (node) also includes the biomass of its own structural elements that is consumed (eaten) by the other nodes. For example, returning to Fig. 1, carnivores eat herbivores, herbivores eat plants, and detritus feeders eat the remainders of the deceased organisms. The output of a functional node therefore also defines the required reproduction of itself (size and composition) to compensate for what has been eaten by the others. Indeed, the organized scheme of expected relations in the ecosystem is based on an internal cannibalism among the elements, and this is what keeps the relative sizes of the network nodes in quasi-steady state.

Given these characteristics, in a natural ecosystem we can calculate the relative amounts of biomass that can be supported in the different functional nodes. Odum (1971b) referred to this as the transformity ratios. For example, 1 kg of tiger requires an average area of plant activity of 1,400,000 m^2 (Karanth et al. 2004). This forced relation depends on the amount of energy consumed per kilogram by secondary carnivores (e.g., tigers), the density of herbivores in the ecosystem, and the productivity of plants per unit of area. The higher the level of energy consumption per kilogram of a functional node, the smaller must be its relative mass (size of the node) in relation to the mass of the nodes that are lower in the food chain (Krebs 2002; Odum 1971a). Hence, the higher the level of consumption of a top node, the lower must be its density in a natural ecosystem. If we find tigers at a density of 1 kg per 100 m^2, this simply indicates that the metabolic pattern that is keeping them alive is not based on ecological, natural regulation. Such extremely high density is possible only in a zoo where the availability of external inputs (meat purchased from the market) circumvents the constraints imposed by the impredicative set of relations between functional and structural elements of natural ecosystems.

The reader may wonder what all of this has to do with bioeconomy. The answer—as will become evident in the next sections—lies in the recognition that all biological (complex) systems, including human beings and human societies, express metabolic patterns that can be stable (sustainable) for extended periods of time provided they respect a forced set of impredicative relations over the characteristics (identity) of their structural and functional elements, which are operating, simultaneously, across a series of organizational levels and scales. The currently popular praxis of "nature as a mentor", propagated by the EU to implement the bioeconomy, does not recognize that the different elements of ecosystems and human social practices affect and are affected by each other (Skene 2021). The phenomenon of group-autocatalysis forces structural elements to reproduce their own identity (autopoiesis), but at the same time, their identity must contribute to the generation of an emergent property—the identity of the whole network. The latter must respect the integrity of its environment. Given that these impredicative relations are established across processes operating at different scales, they not only defy the logic of reductionist science, but can only be observed by adopting non-equivalent descriptive domains and using different metrics. This feature has profound implications for the analysis of the metabolism of human society, and hence the biophysical feasibility of a bioeconomy.

Rupture of the equilibrium between society and environment: the metabolic rift

The industrial revolution (from around 1760 to roughly 1820–1840) represented a drastic rupture of the mechanisms of interaction between human activity and ecological processes. This rupture was generated by interrelated, radical changes in the institutional, social, technical, and biophysical organization of society. The contemporary surge of capitalism guaranteed the requisite institutional changes that reshuffled both social relations and the traditional practices of consumption and production. These changes were driven by a promethean ideology of exploitation of nature (at odds with the mentoring of nature) that boosted scientific developments and technological innovations enabling the use of new resources (e.g., fossil energy, steam power) and new production techniques(e.g., mechanization of manufacturing and agriculture, production of fertilizers in agriculture, see Foster 1999). Karl Marx, in his analysis of the consequences of the second agrarian revolution in Europe (1830–1890), already described this rupture in relation to the complex scheme of organization of living systems outlined in the previous section. As detailed by Foster (2000), Marx, in his opus magnum "Das Kapital—Kritik der politischen ökonomie", used the concepts of *metabolism* (*stoffwechsel*), defined as "a process between man and nature, a process by which man, through his own actions, mediates, regulates and controls the metabolism between himself and nature", and *irreparable rift* (in this metabolism), defined as "a result of capitalist relations of production and the antagonistic separation of town and country" (p. 141).

The transgression of the rules of biological evolution and the adoption of an entirely new mechanism for expressing the metabolic network of human society had profound implications for the interaction between society and nature. Figure 2 illustrates the long-term consequences of the rift between the original, natural metabolism based on the use of renewable energy sources and traditional social practices (circular economy) and the current metabolism of human society based on the use of non-renewable energy sources, the market economy, and globalization (linear economy).

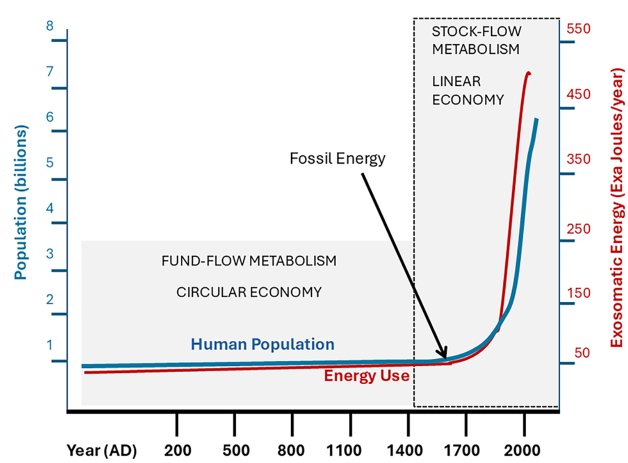

Fig. 2 The consequences of the metabolic rift caused by the shift from biomass to fossil energy

As shown in the graph, for centuries the human population remained stable below the size of one billion people and energy consumption constant around 50 EJ/year (EJ = 1 exajoule equals 10^{18} J), as both population density and energy consumption were limited by the availability of biomass inputs, until the industrial revolution. With the introduction of technological innovation driven by fossil energy use, generalized commodity production, and long-distance trade, modern economies escaped the original set of ecological constraints, disrupting the delicate equilibrium between upward and downward causation in the socio-ecological system.

An alternative view of this rupture with the original set of ecological constraints is given in the two graphs of Fig. 3 (which are both represented on a logarithmic scale). Before the industrial revolution, the economy was circular, as it was based on natural processes of biomass production, gathered and used as energy input by a predominantly rural population. The industrial economy, on the other hand, is linear as it derives its inputs from fossil energy stock depletion and disposes its waste by accumulating emissions in the atmosphere, lithosphere, and the hydrosphere. Comparing the energy supply (left-hand graph) with the energy requirement (right-hand graph), it is evident that the density of the supply of energy inputs in the form of biomass is too low to meet the required power density of the activities carried out by post-industrial societies. The density of the supply of fossil energy is orders of magnitude higher than that of biomass production. It is this feature of fossil energy that has permitted *Homo sapiens* to express a new set of social practices at a density (i.e., urban population) that would simply be impossible if our species would rely exclusively on a natural chain of transformations of biomass into useful energy carriers. Humans have become *alien ultra-carnivores* in their interaction with the surrounding ecosystems: their density and per capita energy consumption have soared to extraordinarily high levels (see Fig. 2). In this regard, the zoo example from the previous section is extremely relevant, because it neatly illustrates how post-industrial and predominantly urban societies are operating: we are basically living in a human controlled zoo, freed from the constraints associated with our natural network niche. No mimicry of natural processes can fix this problem.

It is remarkable that in this path of evolution, the energy consumption per capita has continued to increase (the slope of the curve of energy consumption is steeper than that of the population size), despite a reduction in the availability of natural resources per capita due to the unprecedented population growth (from less than 1 billion to around 8 billion) (Fig. 2). This outcome has been possible because human society moved from a predominantly endosomatic metabolism (converting food energy input into work inside the body) to a predominantly exosomatic metabolism, in which machines replaced human muscles and new forms of energy replaced food as primary energy inputs (Giampietro et al. 2012). The human species now relies on detached (manufactured) devices instead of muscle power that are tightly linked with the structural and functional components of the system. This dramatic change in the transformity ratios inside the metabolic network of human society [the average consumption of exosomatic energy in Europe is about 14 MJ/h, whereas the endosomatic consumption is only 0.6 MJ/h (Giampietro et al. 2012)] would have been impossible without the dramatic change in social relations, institutions, and means of communication in the autopoietic process implied by capitalism.

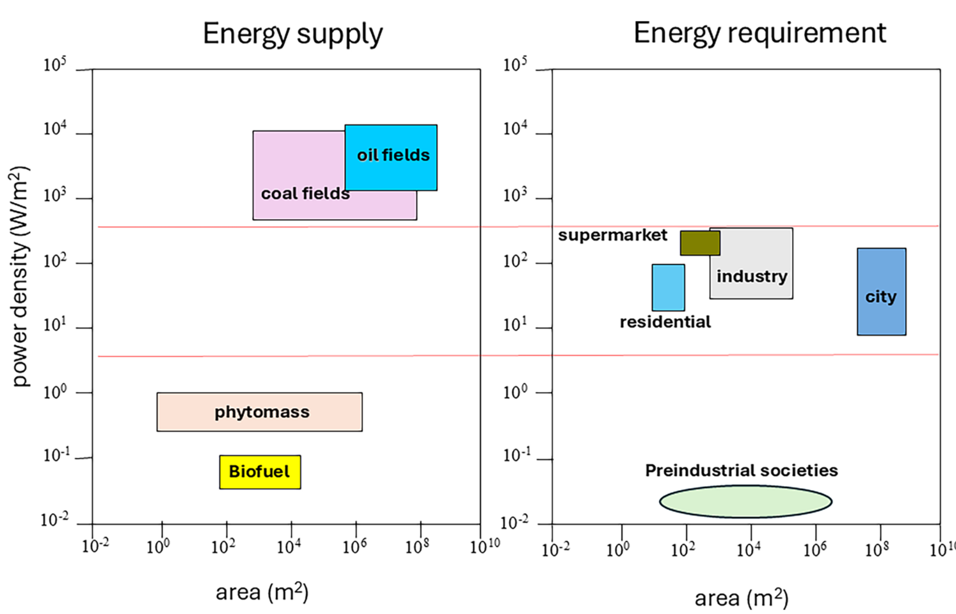

Fig. 3 The power density gap between biomass and fossil energy [adapted from (Smil 2003) with additional data from (Giampietro et al. 1992)]

Nonetheless, despite the metabolic rift, the scale of human activity, in terms of the quantity of energy transformed under human control, remains negligible compared to the total energy transformed by natural biophysical processes on this planet. For instance, the exosomatic energy used by humans in 2021 amounted to 19 TW [595 EJ/year—(BP 2022)], whereas for the water cycle only, Earth dissipates 44,000 TW of solar energy (Taube 1985). This indicates that it is not possible to substitute the services provided by Earth's natural capital with human-made technological capital on a large scale. In the same way, increasing the number of fishing vessels is useless if the number of available fish decline dramatically or to increase the number of fruit trees is pointless if the natural bee population (needed for pollination) is decimated due to pesticide pollution. It is simply impossible to fabricate self-sustaining changes in large ecological networks (operating across various levels of hierarchical organization inside the large-scale bio-geochemical cycles) by tinkering with the individual elements of the ecological network. Despite the presumptuous term "Anthropocene" assigned to the human supremacy following the formation of the metabolic rift (Malhi 2017), this dominance probably will not even last as long as the Roman Empire did. Indeed, it is highly questionable whether we will be able to continue defining our social identity (and population size) in a totally self-referential and promethean way, without considering the state of the environment.

The changing societal identity

We will now show ("The changing societal identity" and "Implausible sociotechnical imaginaries?") that the evolution of the term bioeconomy in the sustainability discourse in the EU is closely linked to the nature of the process generating and updating the identity of human society. To this purpose, we first explain in this section the process of the formation and adaptation of the identity of human society, drawing on complexity science (and in particular the theory of complex adaptive systems) and biosemiotics.

The etymology of the term "identity" derives from the Latin *identidem*—a contraction of *idem* and *idem*—which literally means ''same and same''. Indeed, the very concept of identity is related to the establishment of a recursive mapping between: (1) something that is observed or experienced on the tangible side; and (2) something that is perceived and represented as an expected reference type on the notional side (Giampietro et al. 2006; Giampietro 2024). This feature, typical of complex adaptive systems, has been described with several different narratives:

1. as recipes making processes and processes making recipes (Simon 1996);
2. as genetic information forging the metabolic pattern and the metabolic pattern forging genetic information (Prigogine 1980);
3. as the evolution in time of a self-informed autocatalytic loop (Odum 1971b);
4. as the resonance between communications determining interactions and interactions determining communications (Luhmann 1995).

All these views and concepts share the notion that the ability of complex adaptive systems (e.g., an organism, an ecosystem, a society) to reproduce and adapt depends on the ability to reproduce an identity rooted in a process of resonance between a set of meaningful perceptions and representations on the notional side and a set of feasible (thermodynamically viable) actions on the tangible side.

Although the genetic makeup of humans did not significantly change over the last centuries, the industrial revolution radically changed the metabolic characteristics of human society through the introduction and use of fossil energy stocks and technical devices (an exosomatic metabolism) on the tangible side and new forms of social institutions on the notional side. The creation of this metabolic rift enabled society to rapidly adapt its identity to both external and internal changes. Indeed, the evolution of the identity of a *human society* is markedly different from that of an individual biological species. For example, an instance of rabbit reproduces its identity using its genome (coded information) and therefore its autopoiesis is entirely self-referential (it is not affected by downward causation). It may only be affected by random perturbations (mutations) during the copying of the genetic information, enabling a slow adaptation of the species to which it belongs to the environment through natural selection.

The reproduction of the identity of human society works in an entirely different way. Social identity is not only determined by a common history (original downward causation), but also by a virtual common future, continuously generated by the psychic structure[1] of society (Luhmann 1995). In this theory, social systems interpret the experiences gained through (internal and external) interactions by updating the meaning of their communications about how to reproduce and adapt. This means that humans can adjust their social identity not only on the tangible side by changing the exosomatic elements in the societal metabolism (energy stocks and flows, technology), but also on the notional side

[1] A psychic structure produces a functional organization of communications that generates a range of meaningful contents (Luhmann 1995).

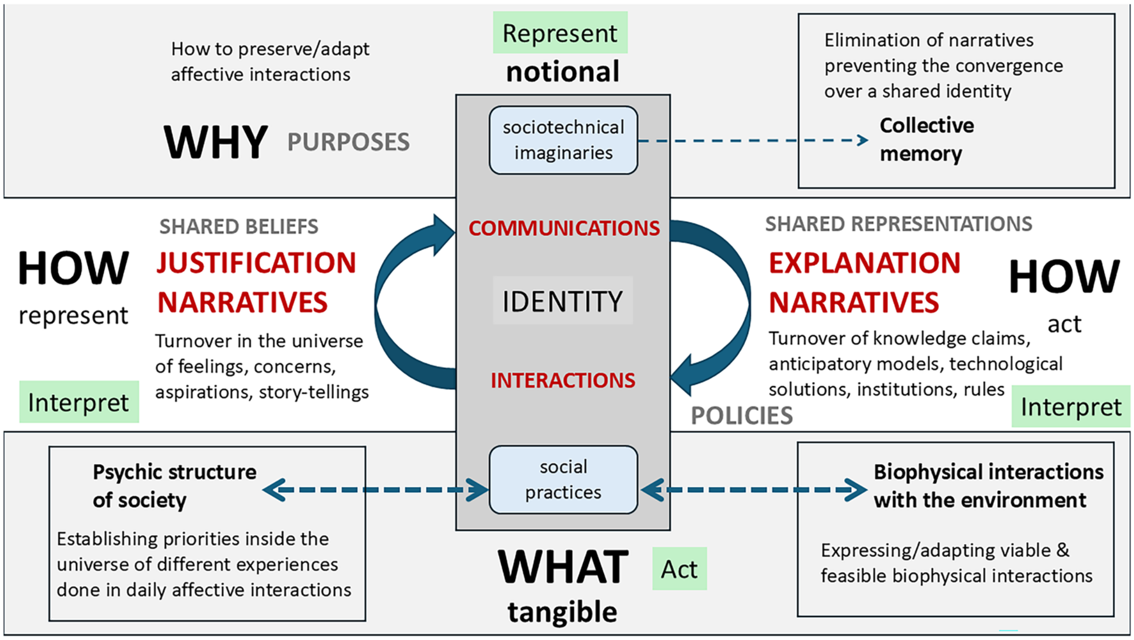

Fig. 4 The biosemiotic process of formation and adaptation of the identity of human society [adapted from (Giampietro 2024)]

by changing their aspirations and shared goals. Hence, by introducing new forms of downward causation (purposes to their life) and new forms of upward causation (technical innovations) the social identity can quickly evolve in time, despite the genetic makeup of the human species remaining the same.

But how to maintain congruity in the resonance between meaningful representations on the notional side (based on purposes, aspirations) and feasible (proven to be thermodynamically viable) and sustainable actions on the tangible side?

Figure 4, drawing on the narrative of biosemiotics of Peirce (1994), and the social theory of Luhmann (1995) shows that this is a complex process in which communication and interaction play an important role:

1. On the tangible side (bottom part of the graph), the interpretation of the experiences gained in the daily affective interactions in the psychic structure of society (left side of Fig. 4) is key to the process. This interpretation is essential for continuously updating the representation of the goals to be achieved according to the shared sociotechnical imaginaries[2] on the notional side.
2. On the notional side (upper part of the graph), the interpretation of the shared representations stored in the collective memory of society is essential for guiding action on the tangible side (right-hand side of Fig. 4). This interpretation, and consequent validation or rejection, is needed to fix or improve the social practices in a way that is compatible with the biophysical interactions sustaining the complex adaptive system as a whole.

As illustrated in Fig. 4 (top part), the sociotechnical imaginaries that the members of a society associate with their societal identity represent what is expected on the notional side and what is stored in the collective memory of the society (Giampietro 2024). On the other hand, the affective experiences gained in performing social practices reflect the perceptions of individuals operating in the psychic structure of the society on the tangible side (bottom part of Fig. 4). In practical terms, it is impossible, at a given point in space and time, to reach an uncontested agreement in society on how to generate a set of shared perceptions/experiences on the tangible side and a shared set of expectations on the notional side, let alone congruity between the two. Hence, the mechanism reproducing and adjusting the identity of human society is not so much about *reaching* a correspondence between the two sides of the identity ("same" and "same"), but rather about *seeking* an acceptable agreement that can provide procedural solutions. [For a more detailed analysis of the process of generation and adaptation

[2] Sociotechnical imaginaries are defined here as: "collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology" (Jasanoff and Kim 2015).

of the identity of human society based on biosemiotics, see (Giampietro 2024).]

Rosen (1985) has argued that of the two sides of the identity of the human society, the notional one (what humans feel and want) is the most important one. Indeed, the promethean ideology that drove the formation of the metabolic rift and that has determined the narratives of neoclassical economics, perceives nature as a resource whose utility depends on human needs and aspirations and assumes that environmental limits can always be avoided using technical innovations. According to this ideology, the preoccupation of humans is not how to integrate into the metabolism of the larger environment (the network/system of which they form part, in line with the strategy adopted by biological systems), but rather how to alter it (the natural organization of biomass across ecological functional compartments) to suit their own perceived needs (e.g., through intensive agriculture, industrialization, urbanization). Yet the number of changes in the characteristics of the larger environment needed to achieve potential aspirations is endless, whereas the room for changing them in a sustainable way is severely constrained. Advocating the term bioeconomy and endorsing the praxis of nature as mentor does not change this predicament.

Implausible sociotechnical imaginaries?

As early as 1979, Habermas (1979) expressed his concern about the existence of a systemic legitimation problem in social welfare state mass democracies. He argued that modern states, having abandoned the nationalistic mechanism of formation of a common identity previously enforced (based on a shared past), have a propensity to base their legitimacy on the idea that they can solve all perceived sustainability challenges with economic progress (a common identity based on shared future expectations), thereby keeping contradictions and conflict under control. Habermas's *prophecy* is present in the European Green Deal, among other policies, promising to transform the EU into a modern, resource-efficient and competitive economy, ensuring zero net emissions of greenhouse gases by 2050, economic growth decoupled from resource use (green growth), and no person and no place left behind (European Commission 2025). Facing this tall order, the only possible solution is the endorsement of and reliance on oversimplified and overly optimistic sociotechnical imaginaries, such as the circular (bio)economy and green growth. Such imaginaries are effective not only in reducing stress ("yes, we can") but also in transforming extremely complex issues, such as sustainability, into mere technical ones that can be solved outside the realm of politics (Funtowicz and Ravetz 1990a; Strassheim and Kettunen 2014; Winner 1989; Wynne 1992).

Hayward (2024, p. 18), drawing on Plato's "Republic", mentions the concept of the noble lie, which he defines as a myth, promulgated by a ruling intellectual elite, with the purpose "to maintain social harmony and the people's acceptance of their social position together with its restrictions which he [Plato] considered integral to maintaining justice in the polity." The unbridled confidence of humankind in its ability to: (1) continuously improve the quality of life and opportunities to succeed of all citizens—that is, the American Dream (Churchwell 2021), and (2) fix all problems with a continuous flow of new business models and technical innovations—i.e., the Cartesian dream of prediction and control (Guimarães Pereira and Funtowicz 2015)—has profound consequences for the functioning of modern society. Indeed, the union of these two dreams in the form of the promethean ideology has determined the systemic choice of policies prioritizing control (e.g., definition of roadmaps) over adaptability (flexible crisis management aimed at learning to adapt to new circumstances).

Rayner (2012), in his paper "The social construction of ignorance in science and environmental policy discourse" argues that the evident success of the use of simplified and optimistic sociotechnical imaginaries in the sustainability discourse [e.g., circular (bio)economy, zero emission in 2050] is not due to a conspiracy of hidden powers, but an outcome of the sense-making processes employed by individuals and institutions. "To make sense of the complexity of the world so that they can act, individuals and institutions need to develop simplified, self-consistent versions of that world. The process of doing so means that much of what is known about the world needs to be excluded from those versions, and in particular that knowledge which is in tension or outright contradiction with those versions must be expunged. This is 'uncomfortable knowledge'" (Rayner 2012, p. 107).

Nonetheless the shared sociotechnical imaginary holding together the European dream (i.e., the fusion of the American and Cartesian dreams supporting the promethean ideology) is increasingly losing credibility, putting at risk the legitimacy of the EU social contract that is supposed to guarantee the core of the professed EU values. The aims of the EU include, among several others, "achieve sustainable development based on balanced economic growth and price stability and a highly competitive market economy with full employment and social progress" and "protect and improve the quality of the environment", and are associated with the values of human dignity, freedom, democracy, equality, rule of law, and human rights (European Union 2025). The preservation of these values depends on a shared belief in prometheanism, i.e., that existing institutions can guarantee sustainable development, perpetual economic growth, social welfare for all, and a healthy environment despite the (ever more evident) existence of biophysical limits. Faced with a growing awareness of a global polycrisis,[3] the diffuse destabilization of social fabric, growing political disaffection, collapse of established international orders, climatic crisis, and shortage of resources hinder a re-discussion of existing institutional arrangements and lock the society into a stubborn denial of the present predicament. This represents a serious threat to the preservation of the integrity of European values and pushes governing authorities to keep the social fabric together around selected oversimplified sociotechnical imaginaries, a precondition to stabilize the flows of subsidies and the welfare state. Can this justify a systemic campaign of policies based on implausible sociotechnical imaginaries—such as green growth through a circular (bio)economy (Giampietro 2019) or rapid zero emission through technical innovations (Smil 2024)—in the process of decision-making? Is the systemic elimination of uncomfortable knowledge from the sustainability discourse compromising the democratic process of quality control of EU policy choices?

Information disorder

To answer these questions and analyze the information disorder in the current political discourse (in our case, related to sustainability), we draw on the work of Hayward (2024) and Wardle and Derakhshan (2017). Wardle and Derakhshan (2017) suggest that the complexity of the phenomenon of information disorder requires a careful reflection on the language used and a critical appraisal of the meaning of terms. To this purpose, they recommend focusing on the mechanism through which the information disorder is hindering the functioning of democracy, and provide three labels to describe specific forms of information disorder:

1. MISinformation: false information that is shared, but that is not intentionally circulated to generate harm.
2. DISinformation: false information that is intentionally circulated to cause harm.
3. MALinformation: genuine information, that, if shared can cause harm (i.e., making information public that should have remained private).

Building on the classification of Wardle and Derakhshan (2017) and Hayward (2024) suggests that to examine the benefits and/or dangers associated with the formation and endorsement of implausible sociotechnical imaginaries and the exclusion of uncomfortable knowledge in political sustainability discussions we need to combine three different frameworks:

1. An epistemic framework to check the lack of robustness of a proposition.
2. A behavioral framework to detect the existence of a strategy to generate false statements to hegemonize a given narrative (or a given explanation about a given concern).
3. A security framework to be used, but only after a proper situated analysis, to identify the risks of harm that may be carried by the communication of certain propositions. Note that this framework, by default, involves a wicked assessment as it requires an uncontested agreement on what (or who) has to be protected against malinformation, why, and how.

It is further helpful to keep in mind the distinction proposed by Carey (1992) between a transmission view of communication and a ritual view of communication. Drawing on this distinction, Wardle and Derakhshan (2017, p.7) observe: “Rather than simply thinking about communication as the transmission of information from one person to another, we must recognize that communication plays a fundamental role in representing shared beliefs. It is not just information, but drama—“a portrayal of the contending forces in the world.” Indeed, “A ritual view of communication is directed not toward the extension of messages in space but toward the maintenance of society in time; not the act of imparting information but the representation of shared beliefs” (Carey 1992).

The graph in Fig. 4 shows that the equilibrium between the shared beliefs (sociotechnical imaginaries) and the shared perceptions and representations (validated experiences gained in the daily social practices) shaping the societal identity requires continuous adjustments through the updating of the justification narratives (what we want to be and what we want to do) and the explanation narratives (what we must do and how). In practical terms, this iteration implies that the interpretation of the experiences (in terms of perceptions and feelings of individuals) must establish priorities over the concerns and aspirations in society to be included in the set of justification narratives adopted by the institutions. In whatever form this prioritizing takes place, it necessarily results in the predominance of a subset of justification narratives eventually included in the official storytelling and stored in the collective memory. The explanation narratives used to guide action (Fig. 4), on the other hand, require that the selected narratives provide a simplified, self-consistent version of the interaction of the

[3] The term polycrisis was first introduced by Morin and Kern (1999) and defined as “a complex intersolidarity of problems, antagonisms, crises, uncontrollable processes, and the general crisis of the planet” (p. 74). For more on the concept of polycrisis, see Lawrence et al. (2024).

society with the rest of the world. Uncomfortable knowledge could prevent the achievement of a convergence between the two sides of the identity. Thus, the formation and adaptation of the identity of a society is based on an institutional hegemonizing of the chosen coupling of justification and explanation narratives.

Combining all these perspectives, we can further elaborate the three categories of information disorder as follows:

1. MISinformation refers to explanation narratives that are unreliable. This judgement does not consider the whole process illustrated in Fig. 4, but simply refers to a certain degree of uncertainty that is naturally inherent in the *transmission* of information. Implausible sociotechnical imaginaries belong to this category, such as the idea of achieving zero emissions while maintaining current social practices.
2. DISinformation refers to a morally unacceptable practice that has the purpose to unfairly hegemonize a selected narrative about a given issue for the benefit of a specific group of social actors. For example, hiding data about the negative effects of a new drug or carrying out a smear campaign against a political opponent. In the field of bioeconomy, there have been several cases of disinformation, notably those benefiting the pro-biofuel lobbies (Cloteau 2020; Nistor 2017; de Oliveira et al. 2017). Disinformation is not only about polluting knowledge claims, but about manipulating beliefs inside the democratic process with the purpose of prioritizing selected narratives to influence decision-making. The purpose here is to impose the aspirations and concerns of a specific group of actors over those of the rest of society.
3. MALinformation is the most difficult concept to handle given that, depending on the perspective adopted, a given proposition can be either dangerous or useful depending on the context and the specific perspectives and concerns present in society. For example, what is positive in the short term, may become negative in the long term and vice versa. This category refers directly to the dilemma posed by uncomfortable knowledge, as we will explain below.

When do implausible sociotechnical imaginaries and the avoidance of specific pieces of uncomfortable knowledge (e.g., the existence of limits to economic growth or the European lifestyle being dependent on a disproportional appropriation of resources at the global scale) become harmful? That is, when do implausible sociotechnical imaginaries become disinformation rather than misinformation and under which circumstances does uncomfortable knowledge (malinformation) become harmful? Hayward (2024, p. 17) argues that this is the case if narratives: "undermine confidence in the institutions whose epistemic authority a society relies on for its democratic functioning, then they could conceivably be argued to compromise a society's capacity to support truthful communication more generally. A democratic society depends on the trust and goodwill of citizens towards each other and towards the system that regulates their interactions. If that trust is severely eroded, there is a risk of system collapse and social crisis." In such case, as suggested by Basham (2018), uncomfortable knowledge can be aptly described as toxic truths.

We thus have a systemic yin-yang tension in society between the need to circulate noble lies (implausible sociotechnical imaginaries) to legitimize existing institutions and strengthen the social fabric, and toxic truths (uncomfortable knowledge) to get rid of obsolete myths so as to enable adaptation and renewal of the societal identity by destabilizing the status quo. Therefore, both noble lies and toxic truths are potentially dangerous, but in different ways. Noble lies are useful to stabilize the status quo when operating in a stable situation. However, when society experiences a situation requiring urgent changes, such as a serious polycrisis, they can generate a situation of Ancient Regime Syndrome. The latter term has been defined by Funtowicz and Ravetz (1994) as: "a state of affairs in which the ruling elites become unable to cope with stressors and adopt instead a strategy of denial, refusing to process either internal or external signals, including those of danger." In these situations, toxic truths (uncomfortable knowledge), because of their disruptive nature, are indispensable for unleashing radical changes in a status quo that is no longer capable of handling crises, even if this represents a clear harm to a given institutional regime. Hence, it is unwise to indiscriminately avoid or fight uncomfortable knowledge/malinformation that rebuts the current sustainability policies based on implausible sociotechnical imaginaries. This will suppress useful criticism of potentially implausible models and narratives used to justify ineffective and expensive political decisions (see, for example, European Environment Agency 2024).

The quality of models, narratives, and political decisions does not depend on their good intentions to solve (in our case) the sustainability predicament. The quality of a political decision depends on the fitness for purpose of the narratives chosen as evidence to inform policy. "A risk in defending a 'noble lie' on the basis of social values, in practice, is that this could materially amount to defending the values of some against the values—or, indeed, against the interests or needs—of others. Whatever justification might be offered for telling a 'noble lie' or concealing a 'toxic truth', in a democracy, the terms of acceptance of that justification, if any, should be in the gift of those affected" (Hayward 2024, p. 19).

Conclusions

> "The crisis consists precisely in the fact that the old is dying and the new cannot be born; in this interregnum a great variety of morbid symptoms appear" (Gramsci 1992, in "Wave of materialism and Crisis of authority", p. 276).

In this paper, we have presented evidence based on the characteristics of complex adaptive systems to illustrate that the concept of bioeconomy is incompatible with the idea of green growth; the mimicry of natural processes simply does not and cannot lead to perpetual economic growth. Elaborating on the biosemiotic process of the formation and adaptation of the societal identity, we have further shown that the current widespread perception of a polycrisis is a sign that, on the tangible side of this process, the mix of current social practices urgently needs change. On the notional side, however, we are still incapable of relinquishing the conventional set of sociotechnical imaginaries grounded in the American and the Cartesian Dreams that is firmly locked in our collective memory. The EU endorsement of the concept of the circular (bio)economy as perpetual economic growth decoupled from resource use (green growth) represents a desperate (not necessarily deliberate) attempt to maintain the status quo through the endorsement of an integrated set of noble lies.

The growing perception in society of the need for urgent and radical changes in our social practices—that is, the need for the legendary "transition"—suggests that, for our own benefit, it would be useful to accept the original interpretation of the concept of bioeconomy. Stopping climate change is not about saving nature, but about saving humankind. Nature can survive without us, but we cannot survive without nature. What is currently required is a beneficial downpour of toxic truths about the impossibility of perpetual economic growth and the necessity of swift substantial changes in what we do and how. Institutions that depend for their legitimacy on a continuous flow of noble lies, end up blinding themselves against the necessary checks to guarantee the quality of their decisions (see Glauda 2024). "When trust in institutions is lacking, the solution is not to engage in strategic communications aimed at making the population more trusting. The solution is to transform the institutions so as to make them more worthy of trust" (Hayward 2024).

Acknowledging that humanity should adapt to the environment rather than ravage it, we should not focus our discussion on how to fix the environment to suit our own needs to avoid changes in our identity, but on how to adapt our societal identity to respect environmental equilibria [i.e., how to go through the tragedy of change—(Funtowicz and Ravetz 1990b)]. In this process, we must decide what aspects of our identity we are willing to lose to retain what we collectively want to sustain.

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