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The Tragedy of Change. How Combining Biosemiotics and Post-Normal Science Can Increase the Quality of the Sustainability Discourse *

La tragedia del cambio. Cómo la combinación de la biosemiótica y la ciencia posnormal puede aumentar la calidad del discurso de la sostenibilidad

A tragédia da mudança. Como a combinação da biossemiótica e da ciência pós-normal pode aumentar a qualidade do discurso da sustentabilidade

Mario Giampietro and Sandra G. F. Bukkens **

This essay illustrates how combining heterodox frameworks provides innovative insights into how the organizational identity of socio-ecological systems reproduces and adapts over time. Understanding these evolutionary dynamics offers crucial information for designing governance processes that manage systemic transitions without triggering structural collapse. We propose a novel narrative framework at the intersection of two fields: i) biosemiotics, focusing on self-organization, semantic closure, organismal agency, and sign-mediated constraints in complex adaptive systems; and ii) post-normal science (PNS), addressing the epistemological challenges of providing knowledge claims for the internal regulatory control of these processes under severe uncertainty and conflicting values. Modern sustainability crises are framed as information disorders, characterized by a growing tension between recorded past-present information (laws, validated knowledge, institutions) and virtual future-present concerns arising from individual interactions with biophysical environments. Finally, we explore how the systemic exclusion of "uncomfortable knowledge" creates zones of hypocognition within governing bodies, locking public policy into unviable pathways. We conclude that an integrated biosemiotic-PNS approach offers a useful methodology to evaluate fitness for purpose of current sustainability metrics.

Keywords: *complex adaptive systems; societal identity; sociotechnical imaginaries; uncomfortable knowledge; governance*

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Este ensayo ilustra cómo la combinación de marcos heterodoxos proporciona perspectivas innovadoras sobre la forma en que la identidad organizacional de los sistemas socioecológicos se reproduce y se adapta a lo largo del tiempo. Comprender estas dinámicas evolutivas ofrece información crucial para diseñar procesos de gobernanza que gestionen las transiciones sistémicas sin desencadenar un colapso estructural. Proponemos un nuevo marco narrativo en la intersección de dos campos: i) la biosemiótica, enfocada en la autoorganización, el cierre semántico, la agencia del organismo y las restricciones mediadas por signos en los sistemas complejos adaptativos; y ii) la ciencia posnormal (PNS), que aborda los desafíos epistemológicos de proporcionar afirmaciones de conocimiento para el control regulatorio interno de estos procesos bajo condiciones de incertidumbre severa y valores en conflicto. Las crisis de sostenibilidad modernas se enmarcan como trastornos de la información, caracterizados por una tensión creciente entre la información registrada del pasado-presente (leyes, conocimiento validado, instituciones) y las preocupaciones virtuales del futuro-presente que surgen de las interacciones individuales con los entornos biofísicos. Finalmente, exploramos cómo la exclusión sistémica del "conocimiento incómodo" crea zonas de hipocognición dentro de los órganos de gobierno, bloqueando las políticas públicas en vías inviables. Concluimos que un enfoque integrado de la biosemiótica y la PNS ofrece una metodología útil para evaluar la adecuación al propósito de las métricas de sostenibilidad actuales.

Palabras clave: sistemas complejos adaptativos; identidad social; imaginarios sociotécnicos; conocimiento incómodo; gobernanza

Este ensaio ilustra como a combinação de referenciais heterodoxos fornece perspetivas inovadoras sobre a forma como a identidade organizacional dos sistemas socioecológicos se reproduz e se adapta ao longo do tempo. Compreender estas dinâmicas evolutivas oferece informações crucials para o desenho de processos de governança que giram as transições sistémicas sem desencadear um colapso estrutural. Propomos um novo quadro narrativo na interseção de dois campos: i) a biossemiótica, focada na auto-organização, no fecho semântico, na agência do organismo e nas restrições mediadas por signos em sistemas complexos adaptativos; e ii) a ciência pós-normal (CPN), que aborda os desafios epistemológicos de fornecer alegações de conhecimento para o controlo regulatório interno destes processos sob condições de incerteza severa e valores em conflito. As crises de sustentabilidade modernas são enquadradas como distúrbios de informação, caracterizados por uma tensão crescente entre a informação registada do passado-presente (leis, conhecimento validado, instituições) e as preocupações virtuais do futuro-presente resultantes das interações individuais com os ambientes biofísicos. Finalmente, exploramos como a exclusão sistémica do "conhecimento desconfortável" cria zonas de hipocognição nos órgãos de governação, bloqueando as políticas públicas em caminhos inviáveis. Concluímos que uma abordagem integrada da biossemiótica e da CPN oferece uma metodologia útil para avaliar a adequação aos objetivos das métricas de sustentabilidade atuais.

Palavras-chave: sistemas complexos adaptativos; identidade societal; imaginários sociotécnicos; conhecimento desconfortável; governança

Introduction

The long-term survival, historical continuity, and structural stability of socio-ecological networks depend fundamentally on their capacity to preserve an internal organizational identity while simultaneously adapting to the shifting and unyielding physical boundary conditions of the biosphere (Nielsen, 2000; Nielsen & Ulanowicz, 2011). In the current historical landscape, this delicate evolutionary balancing act faces unprecedented levels of destabilization. Global polycrises—visible in climate volatility, massive systemic biodiversity degradation, topsoil depletion, financial turmoil, and the approaching limits of natural resources—demonstrate that modern institutional governance mechanisms are increasingly incapable of processing physical feedback from the ecosystems that embed them (Nielsen, 2016).

This breakdown in institutional regulatory capacity reveals that our collective socio-economic structures are suffering from an epistemic crisis. We have built governance models that decouple abstract financial and political sign-systems from actual thermodynamic realities. The study of this intersection is no longer merely an academic luxury or an isolated philosophical exercise; it constitutes a critical requirement for survival, directly affected by collective concerns and fears. If collective decision-making processes fail to correctly interpret and respond to environmental warning signs, the historical pattern of complex societal collapse (Tainter, 1988) ceases to be a historical curiosity and becomes an unavoidable certainty. The central challenge of sustainability is to discover how a self-referential system can alter its own internal values and structural habits before material resource exhaustion forces a chaotic transformation from the outside.

1. Why biosemiotics?

For over a century, traditional science has attempted to resolve the relationship between organizational stability and external material dynamics through reductionist, quantitative models (López-Díaz & Gershenson, 2025). Early attempts, rooted in classical physics and later non-equilibrium thermodynamics, explored whether the persistence of living systems could be accounted for by universal laws of energy dissipation (López-Díaz & Gershenson; Nielsen, 2000; Prigogine, 1980). This fundamental dilemma was summarized by Karl Pearson in his 1892 classic *The Grammar of Science*, where he questioned how science could distinguish the living from the lifeless if both were described conceptually by the microscopic motion of inorganic corpuscles (López-Díaz & Gershenson, 2025). This inquiry highlighted the limits of pure physical mechanism: it lacked any conceptual vocabulary to describe purpose, intent, or functional selection.

It is lesser known that the concept of metabolism is also used in the field of energetics (pioneered by Ostwald, 1907, 1911), where it refers to the relation between energy transformations and the organization of human society, i.e., societal metabolism (Fischer-Kowalski, 1998; Fischer-Kowalski & Hüttler, 1998; Georgescu-Roegen, 1971, 1975, 1977; Giampietro, 1997; Giampietro *et al.*, 1997; Hall *et al.*, 1986; Odum, 1971; Prigogine, 1980; White, 1943; Zipf, 1941).

The mid-twentieth-century explosion in molecular biology, culminating in the mapping of DNA, temporarily sidelined these concerns by establishing a rigid, genocentric paradigm (López-Díaz & Gershenson, 2025; O Nualláin, 2014). Information was redefined as a passive, linear sequence of instructions, and organisms were framed as complex machine-like vehicles built to maximize the replication of code fragments (O Nualláin, 2014). Concurrently, complex systems science emerged to offer an alternative, non-reductionist narrative (López-Díaz & Gershenson, 2025). It framed living systems, ecosystems, and human societies as self-organizing, non-linear networks characterized by emergent behavior, feedback loops, and spontaneous order (López-Díaz & Gershenson, 2025; Nielsen, 2016).

In the development of complex systems theory, Herbert Simon (1962, 1996), one of the pioneers of complexity theory, proposed a narrative to describe the common pattern of self-organization used by these systems. They are produced and reproduced through an iterative process in which recipes (a formal, step-by-step notional description of a process) make processes (biophysical interactions constituted by organizational activities that generate, select, and execute those recipes), which in turn reproduce the recipes. Furthermore, this dynamic interplay shows that reducing lower-level mechanical degrees of freedom can paradoxically generate and amplify higher-level evolutionary and semiotic freedom (Zhou, 2023).

In applying non-equilibrium thermodynamics to the analysis of biological systems, Ilya Prigogine (1980) and Prigogine and Stengers (1984) identified the same organization in the functioning of biological systems. Genetic information recorded in the genotype (notional representations) drives communication across different functional components of biological systems, leading to biophysical processes that realize physical organisms—the phenotypes. In turn, the organisms belonging to that phenotype express a metabolic activity that copies and duplicates the original descriptions used to generate it.

In ecology, systems thinkers like H.T. Odum (1971) integrated these insights with thermodynamics, describing ecosystems as self-informed, autocatalytic loops that capture exergy and dissipate entropy (Nielsen, 2000). Again, in these narratives, we find a standard pattern in which “effective representations” allow effective communication, translating into “biophysical interactions” that generate an emergent property of the whole: the ability to reproduce the various steps of the process. Margalef (1967) beautifully captured this self-referential property by describing ecosystems as networks of “systems sending messages to themselves into the future”. This perspective has been extended into contemporary structuralist iterations highlighting that organismal agency and purpose are definitive characteristics of life that cannot be captured by purely genocentric or reductionist frameworks (Jaroš, 2025; Nielsen & Müller, 2000; Svorcova, 2024).

Finally, regarding the subject of this paper, a significant step forward in the social sciences was driven by the work of Niklas Luhmann (1986, 1995). Luhmann made it possible to apply the conceptualization of the biosemiotic narrative to the processes through which a society defines, preserves, and adapts its identity. Luhmann views

society as a network of meaningful communications stabilized through resonance between representations of processes taking place in society and actual interactions on the biophysical side, occurring both inside and outside society (Luhmann, 2009). This narrative builds on Habermas (1979) regarding communicative action—the need to establish a shared feeling of belonging to a community sharing common objectives—and on the concepts of exosomatic and endosomatic metabolism proposed by Lotka (1956), Georgescu-Roegen (1971), and Giampietro *et al.* (2012), which highlight the necessity of respecting biophysical constraints in the processes taking place on the tangible side.

This pattern of organization is highly complex because it involves impredicative relations among the interacting parts (which mutually construct each other), as well as a multilevel organization between the parts and the whole. This complex organization permits the system to express emergent behavior, enabling it to simultaneously reproduce and adapt to changing circumstances (becoming a cohesive system) across different scales.

Human societies share the basic organization of the biosemiotic process found in biological systems:

- self-referential autopoiesis of parts based on codes that preserve the identity of reproduced elements over time;
- structural coupling of parts-to-whole and whole-to-context informed by semiotic controls, keeping the dissipative system viable in its metabolic pattern;
- the establishment of a functional cycle that evaluates the meaning of identity within a given context, managing to integrate system activity with its surrounding environment.

However, compared to biological systems, the reproduction of human societal identity works in an entirely different way. Societal identity is determined not only by a common history (downward causation) but also by a virtual, common future continuously generated by the psychic structure of society at the individual level (Luhmann, 1995). This means humans can adjust their social identity not only by changing the structural elements in societal metabolism (institutions and technology) but also by altering their beliefs, values, and aspirations (ethical dimension). Consequently, they can introduce both new forms of downward causation (purposes for their life) and new forms of upward causation (technical innovations). In this way, societal identity can quickly evolve over time despite the genetic makeup of the human species remaining unchanged. This explains the evolutionary success of the human species over others on this planet.

Therefore, the narrative of biosemiotics demands that we abandon the classical analytical straitjacket of reductionism. This complex organization implies that complex adaptive systems are neither purely tangible nor purely notional; rather, they are both, with the two sides interwoven in a complex, dynamic manner.

Biosemiotics is an interdisciplinary domain of scientific inquiry in which biologists, philosophers, theoretical ecologists, complex systems scientists, systems theorists, and social scientists collaborate to develop a coherent narrative. In recent decades, this domain has become an important and respected scientific field of inquiry, characterized by an explosion of international conferences, international societies, peer-reviewed journals, and book series. However, the basic ideas and discussions taking place in this field remain largely unknown within the broader scientific and academic communities. For this reason, it is extremely difficult to provide effective, specific references on particular issues to individuals who are unfamiliar with these topics. In response to this challenge, the tendency in the field has been to generate introductory pieces authored by leading experts that provide a holistic view of this scientific domain (Andrade, 2007; Favareau, 2011; Kull *et al.*, 2009, 2011; Kull & Favareau, 2022; Queiroz *et al.*, 2011; Robuschi 2020; Vehkavaara & Sharov, 2017). Alternatively, other references do not address biosemiotics directly but focus on conceptual issues key to understanding its implications for the functioning of complex adaptive systems (Nielsen, 2000; Nielsen, 2007), as well as critical comparative evaluations mapping Peircean frameworks against contemporary code-semiotics (Brier & Joslyn, 2013).

2. The pressing need for post-normal science

Post-normal science calls for a careful and detailed evaluation of the quality of the process informing policy decisions under high levels of uncertainty, rather than evaluating the quality of the advice itself (Funtowicz & Ravetz, 1990, 1993). Compared to the traditional evidence-based policymaking approach (which checks only the quality of the final advice), moving the focus to the quality of the process introduces a notable complexification of the issue (Saltelli & Giampietro, 2017; Turnpenny *et al.*, 2010). Indeed, if we consider the entire process leading to a given decision, relevant factors must include not only the robustness of the knowledge claims used to inform decision-makers but also the endorsement of values, choices of purpose, and strategies adopted for handling uncertainty. As argued by Kønig *et al.* (2017, p. 13): "it should still be clear that the norms and values of the different problem-solving strategies depend on and are developed under different conditions of problem solving". This automatically entails that we cannot expect to find a single "best possible" solution to our problems.

Post-normal science has been primarily applied in the fields of environmental and sustainability sciences, where dilemmas inherently involve high uncertainty and competing stakeholder interests (see, for example, Francis & Goodman, 2010; Krauss *et al.*, 2012; Petersen *et al.*, 2011), and in public health and epidemiology, where medical science intersects with urgent public policy and human behavior—the COVID-19 pandemic being an iconic example (see, for example, Ravetz, 2020; Waltner-Toews *et al.*, 2020; Mongeon *et al.*, 2025). These applications have shown that when decision-making requires the ability to properly integrate rules and values under specific (and sometimes highly exceptional) circumstances, we must guarantee a process capable of endorsing both rules and values in relation to the decisions to be taken.

In this context, it is important to recognize that the process is not so much about reaching an absolute consensus but rather about seeking an agreement that can provide procedural solutions. This is where the insights provided by biosemiotics become essential. In fact, evaluated within the biosemiotic narrative, we can easily understand that the role of controls in the process (how to translate norms, rules, knowledge claims, and sociotechnical imaginaries existing in society into decision-making) is crucial in the field of science for governance. Regarding the overall task of preserving and adapting societal identity, how can we separate passion from reason when society is faced with the need to continuously update the existing set of values and rules that determine its social identity in response to environmental challenges?

There are three distinct families of narratives operating in the semiotic process:

- Justification narratives refer to the identification of societal concerns and a common purpose. They justify *why* action is needed.
- Explanation narratives refer to the "evidence" used to support the validity of the problem structuring, i.e., *how* we can address concerns and achieve the common purpose. This does not necessarily refer only to scientific "evidence"; it may also concern traditional knowledge, religious convictions, and sociotechnical imaginaries. The latter are generally accepted as feasible but may be mere wishful thinking (see Section 4).
- Normative narratives refer to the targets and results to be achieved. They dictate *what* must be done to implement the action toward achieving the chosen goals. This involves institutions, law enforcement, European Commission directives, etc.

In their daily social practices, the perceptions of local groups of interacting agents coalesce into a shared understanding of concerns, leading to the adoption of common narratives (shared beliefs about causality over relevant events) that justify actions. When these shared narratives about perceived threats or opportunities reach a critical mass, the issues become politically relevant. They are then used as inputs for relevant communications on the notional side. Here, scientific inquiry selects the corresponding "proper" (i.e., relevant and reliable) representations, which are then recorded as validated knowledge claims (societal memory) and utilized by the control system.

Wrapping up the recursive relation among the three narratives: (i) the *why* reflects the history of society and defines the final causes that must be addressed; (ii) the *how* refers to the collective knowledge accumulated by society about the present situation and the option space; and (iii) the *what* is determined by the ontologies and narratives used to describe and anticipate the effects of its actions on the tangible side. The *what* includes not only the definition of external action but also decisions about internal system organization (such as institutional settings, tax systems, and social benefits). In this process, individual feelings play a key role within the biosemiotic process by judging the quality of the overall system: they answer whether the efforts required from individual members of society were worth the burden. They address the fundamental question of whether the collective efforts of society's members truly yielded worthwhile results, an

area increasingly studied via multi-level psychodynamic and bioenergy frameworks that map personal well-being directly onto wider macro-semiotic constructs (Goli, 2025).

Thus, the three narratives about *why*, *what*, and *how* affect each other in an impredicative way; therefore, their quality cannot be discussed in isolation. The entanglement between passion (the *why*) and reason (the *how*) is unavoidable and key to the proper functioning of the semiotic process in relation to the selection of effective policies, which must be mediated by the political process (the *what*). Indeed, the quality of scientific input to policymaking is systematically affected by four factors that should be considered simultaneously:

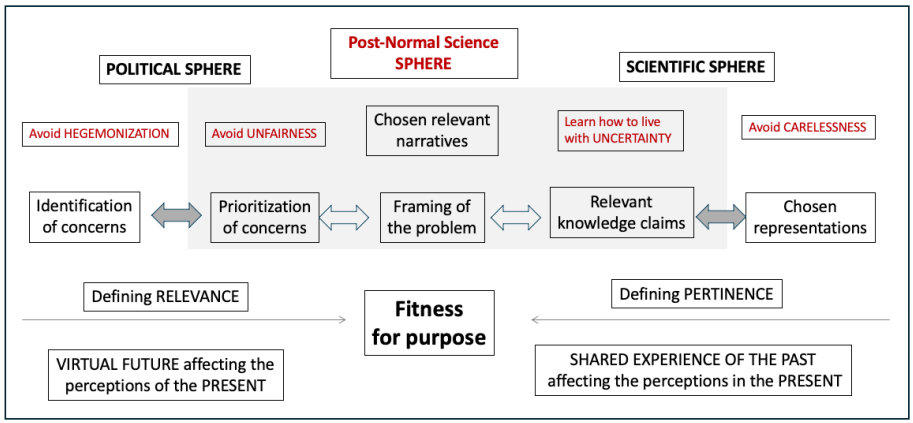
- *(Un)fairness:* This refers to the filtering of an infinitude of individual concerns into a limited set of societal concerns to be addressed. It is critical to decide how to select among the different narratives found in society: who decides, and how do we prioritize the stories populating the sustainability discourse?
- *Hegemonization:* This refers to the step of setting priorities in selecting societal concerns to be addressed and implementing policies regarding those concerns.
- *Hypocognition:* This refers to the step of selecting useful representations for informing policy. It is essential to be aware of possible 'unknown unknowns' or 'unknown knowns' in this selection process. 'Unknown unknowns' or 'unknown knowns' may be neglected or purposefully ignored in the selection of 'valid or relevant knowledge' (hypocognition), while familiar concepts (known knowns) may be over-applied to situations where they do not fit (hypercognition) (Giampietro & Bukkens, 2022).
- *Uncertainty:* This refers to the aggregate effect of the previous three factors on the quality of the entire biosemiotic process. Considering the whole process, uncertainty is unavoidable and represents an essential factor to recognize. Depending on the type of decision required, uncertainty can become extremely relevant.

From the section above, it is evident that science occupies a peculiar place in the biosemiotic process. According to Luhmann (1995), and in line with the concept of scientific 'evidence', science is based on the binary principle of true/false. However, within a biosemiotic process, science cannot provide a generalized criterion of truth. Within a biosemiotic process, the quality of a given scientific explanation depends on the usefulness and desirability of the results obtained when applying it. That is, setting aside uncertainty, if we acknowledge that science can only provide explanation narratives, then depending on the purpose of the analysis, science can only be useful or irrelevant. For this reason, we suggest adopting a different quality code for science, moving from the idea of scientific evidence (true/false) to scientific explanation (useful/irrelevant). This is where post-normal science is key.

A conceptual illustration of how post-normal science can be seen as a problem-solving procedure in the biosemiotic process, integrating the scientific and political spheres, is shown in **Figure 1**. The set of impredicative relations illustrated in **Figure 1**

shows that before deciding on a specific scientific problem-framing (moving from left to right), it is necessary to explore relevant concerns in society and to establish priorities over these concerns to articulate the justification narratives that will guide the choice of explanation narratives. At the same time, an analogous process of selection (moving from right to left) must be carried out regarding the pertinence of scientific information—i.e., the choice of narratives and ontologies—and the individuation of knowledge claims providing relevant insights into how to properly frame the selected concerns.

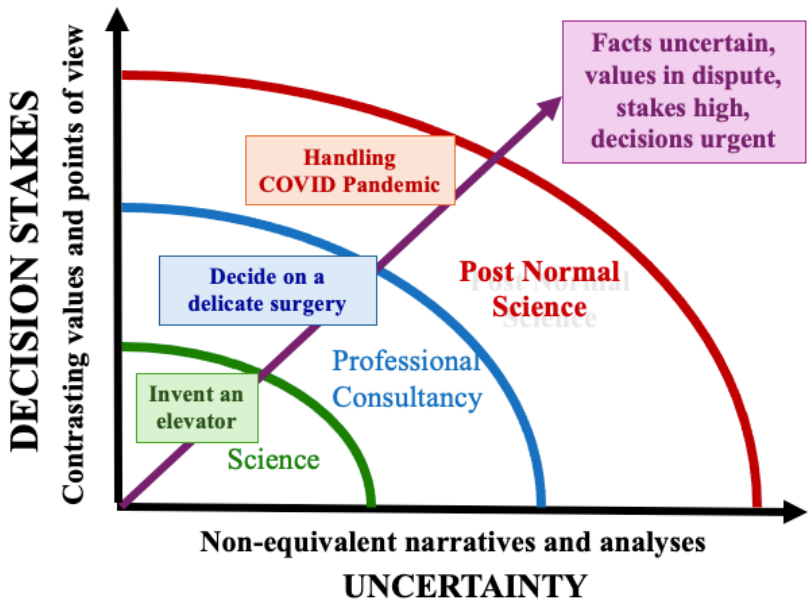
Figure 1. Post-normal science as a problem-solving procedure in the biosemiotics process



Source: own elaboration.

The inputs coming from the political sphere must be validated by processes taking place in the notional system (individual feelings, ideologies, concerns), while inputs coming from the scientific sphere reflect the existing set of validated communications recorded in societal memory and institutionalized in scientific inquiry. The two sets of inputs must be integrated within a process of reciprocal entailment; concerns can be defined as wrong by new scientific explanations, while explanations can be classified as irrelevant by new concerns. This dynamic and reciprocal entanglement implies that optimal solutions based solely on the results of scientific inquiry are an illusion. Indeed, one of the major insights of post-normal science is that the quality of scientific information used for governance depends on its fitness for function or purpose (Funtowicz & Ravetz, 1993, 1994, 1997). Hence, the quality check on information generated and used to guide action must encompass all steps of the biosemiotic process.

Figure 2. Post-normal science described through a biosemiotics lens



Source: own elaboration (after Funtowicz & Ravetz, 2020).

Figure 2 shows an alternative version of the iconic graph of post-normal science based on the biosemiotic narrative. The vertical axis represents the pre-analytical choice of justification narratives—that is, *why* action is needed and the related decision stake. The horizontal axis represents explanation narratives (*how* to take action to deal with specific concerns) and the corresponding uncertainty related to the coexistence of a variety of different perceptions and representations of knowledge claims endorsed by society.

The systemic level of ignorance about "the external world" means these representations cannot be completely trusted. Given the complexity of social systems, the mix of perceptions and representations used to model them cannot properly predict the future results of interactions taking place on the tangible side of the socio-ecological system across all dimensions and levels of analysis. Models making climate change predictions are a prime example of this problem; uncertainty is unavoidable.

The diagram of post-normal science shown in **Figure 2** reflects different typologies of problem-solving strategies to decide *what* action should be taken. Three common problem-solving strategies include:

- *Applied science*: This strategy is useful when dealing with validated types of social practices, such as constructing a parking garage. In this case, we have a clear consensus on the definition of concerns to be addressed (the *why*; vertical axis of **Figure 2**) and a clear consensus on relevant perceptions and representations (the *how*) to establish an uncontested problem structuring (the *what*). In this situation, two quality checks are needed: on the rigor of the analysis (application of validated knowledge claims) and on the possibility that the given problem structuring is missing "unknown unknowns" or "unknown knowns" (Giampietro & Bukkens, 2022). Hence, even when relying on validated knowledge, one must always be aware of the possible presence of hypocognition (Lakoff, 2010). In this case, the moral responsibility of the scientist refers to the quality of the disciplinary work delivered. This moral responsibility demands a reflexive appraisal of the limits of applicability of their own domain of expertise in relation to the given problem.
- *Professional consultancy:* This strategy is useful when dealing with a unique instance of social practice, such as performing a newly developed surgery. In this case, relevant concerns coexist and require prioritization before deciding what to do. This involves evaluating different coexisting perceptions and representations of the consequences of the action (for both the surgeon and the patient). In this situation, the moral responsibility of the choice of action must be shared between scientists and those affected by the decision. Quality checks in this problem-solving strategy must consider potential carelessness and hegemonization on the part of the expert (e.g., downplaying risks in the fervor of attempting a new procedure) as well as the hypocognition unavoidably related to new techniques. The choice of consultant matters significantly, as do the characteristics of the patient, and consulting several different experts is highly recommended when adopting this strategy.
- *Post-normal science:* This strategy is useful for addressing new perceptions of concerns (*why*), corresponding required new representations (*how*), and new policies and measures (*what*) to update social practices. Relevant examples include the efforts of the European Commission and national governments to transition to a low-carbon economy, or the handling of the COVID-19 pandemic. As shown in **Figure 2**, these situations invariably involve legitimate, contrasting concerns, interests, and aspirations, diverging opinions about prioritization, and new, untested representations. This makes it impossible to arrive at a robust grand narrative indicating a singular best course of action, presenting a formidable challenge to scientists and policymakers alike (Giampietro & Kovacic, 2019). In the case of urgent decisions, respecting all required quality checks can become an impossible mission. The issue of fairness, though highly relevant, becomes particularly difficult to address properly: how do we reach a "fair" agreement on whose feelings and interests regarding shared purposes, prime concerns, and socio-technical imaginaries should be prioritized over others? This situation represents what Funtowicz and Ravetz (1990, 1994) term the "tragedy of change".

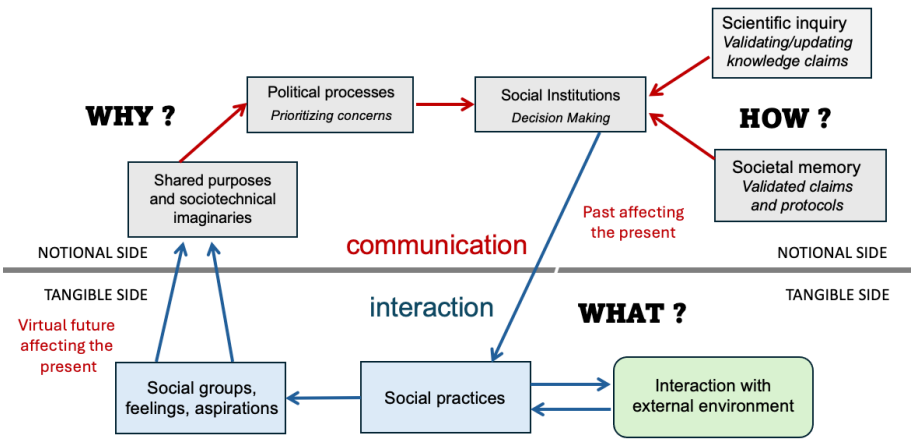
3. The process of preserving and adapting societal identity

All these views and concepts share the notion that the unique ability of complex adaptive systems (e.g., organisms, ecosystems, societies) to reproduce and adapt their identity is rooted in a process of resonance between a set of meaningful, semiotically robust representations on the notional side and a set of feasible (thermodynamically viable) actions on the tangible side. This process of resonance is the result of balancing two competing needs:

1. Maintaining the fit, at any given moment, between actual expectations (on the notional side) and actual biophysical realizations (on the tangible side).
2. Guaranteeing future adaptation to changes over time in either environmental boundary conditions (changing external conditions) or the social fabric (changing initial conditions).

This balancing act of maintaining the status quo while simultaneously allowing for change depends on establishing and maintaining effective communication among society's members, who share their experiences regarding prior interactions with society and the external environment. This is shown schematically in **Figure 3**. This figure is divided into two parts: the upper part represents events taking place on the notional side of the system, while the bottom part represents events taking place on the tangible side. The two parts must stabilize each other in an impredicative set of relations to generate, preserve, and adapt the following basic elements:

Figure 3. The biosemiotic process of formation and adaptation of the identity of human society



Source: own elaboration.

On the notional side, the biosemiotic process must generate:

- A set of shared purposes that justify the commitment of society's members to operate together toward the reproduction and adaptation of an accepted identity. Members of society, through mutual communication, must share the feeling that the chosen identity is desirable and feasible—that it is worth the burden it entails. A given identity must be associated with a sociotechnical imaginary about the future (Jasanoff & Kim, 2015). It is precisely this shared feeling (moral power) that legitimizes institutions and validates the recorded knowledge of society (suggesting updates or even revolutions when deemed necessary). The goals and dreams to be achieved must be shared by the social group rather than by individuals.
- A corpus of validated knowledge claims used to organize and exploit the experience accumulated in interactions with the external world (represented by scientific inquiry and societal memory components). This knowledge is organized into taxonomies of narratives, ontologies, and recorded data used in representing the external world, and it guides action through the definition of institutions, protocols, rules, and controls.

On the tangible side, the biosemiotic process must guarantee the well-being (regarding feelings and emotions) of various social groups, maintain an integrated set of social practices (Schatzki, 1996), and respect the ecological processes required for an admissible environment (boundary conditions). The latter is a crucial but complex constraint, as environmental admissibility does not depend solely on activities carried out inside the social system, but also on the characteristics of embedding ecosystems and the activities of other social systems with which society trades. That is, it depends on the characteristics of remote ecosystems and international trade activities.

Hence, environmental admissibility is not fully under the control of society's self-organizing process. This dependence on external processes entails systemic uncertainty regarding the validity of information stored inside the system. The more a society boosts its autopoietic activity, strengthening its internal identity, the more it increases its impact on the external environment. As proven historically (Tainter, 1988) and evident today, the over-exploitation of embedding and remote environments, alongside dependence on external societies, tends to destabilize and ultimately endanger the societal process of self-organization over the long term.

On the notional side (upper half of **Figure 3**), interpreting the shared representations stored in collective memory is essential for guiding action (right-hand side of **Figure 3**). This interpretation, along with consequent validation or rejection, is needed to fix or improve social practices on the tangible side through modifications to data, models, rules, controls, and institutions. Hence, to stabilize the resonance between the notional and tangible sides, the social system must guarantee:

- *On the notional side:* An effective system of communication capable of preserving and expanding the meanings used to define and update the expected states of society.
- *On the tangible side:* An effective system of tangible controls over the network of biophysical interactions, ensuring that social practices operate within an admissible environment.

In practical terms, it is impossible at any given point in space and time to reach an uncontested agreement in society on a shared set of experiences gained on the tangible side and a shared set of expectations defined on the notional side, let alone perfect congruity between the two. Hence, the mechanism reproducing and adjusting human societal identity is not about reaching an exact correspondence between both sides ("same" and "same"), but rather about seeking an acceptable agreement that can provide procedural solutions (for a more detailed analysis, see Giampietro, 2024).

Robert Rosen (1985) argued that of the two sides of human societal identity, the notional one (shared purposes and sociotechnical imaginaries) is the most critical. Indeed, humans tend to colonize their environment rather than adapt to it; they seek to overcome the biophysical factors that limit the expression of their desired social identity. The primary focus of human society is not centered on harmoniously integrating into the complex ecological network of which it forms a part, but rather on altering that network to suit its own desires and perceived needs (e.g., through intensive agriculture, industrialization, and urbanization). While the changes required to meet current human aspirations are profound and endless, the scope for changing environments in a sustainable way is severely constrained. This is precisely where environmental problems (climate change, soil erosion, pollution, habitat destruction) unavoidably emerge.

As described previously, in the process of self-organization on the tangible side, the "criterion of truth" for information inputs used in the societal control system is represented by the proven ability of society to reproduce and adapt the tangible structural and functional components needed to achieve the desired configuration for its members. Hence, self-organization on the tangible side is about reproducing a given set of expected interactions with the external world, referred to as structural coupling (Maturana & Varela, 1992). The information used to achieve and stabilize structural coupling only addresses the technical and tangible interactions needed to stabilize the metabolic pattern of society; it does not address individual feelings, perceptions, or values. Nonetheless, the justification for reproducing structural coupling (the *why*) refers to the *entire* process of self-organization and autopoiesis, flagging the importance of a generalized acceptance of the perceived desirability of social practices at the individual level.

Preserving coherence over established and expected social roles translates into preserving a "group identity" that is essential for effective communication based on a shared language. In other words, to communicate, humans must share a common purpose (Habermas, 1979). Using this group identity, individual members of society can establish a self-referential process bundling together their shared feelings, allowing the

endorsement of a common purpose via sociotechnical imaginaries (Jasanoff & Kim, 2015). The perception of shared feelings about a common purpose allows the formation of a social fabric that holds members together and enables the integration of social practices across different organizational levels (Schatzki, 1996). This underscores how human self-organization relies on balancing somatic interoception, individual drives, and collective narratives to avoid existential friction (Goli, 2025).

The definition of a common purpose justifies collaborative action (the *why*) and legitimizes the institutions that enforce social decisions (the *how*). Without a robust social fabric, individual members would lose their feeling of belonging, making it impossible to decide how to preserve and adapt integrated social practices. To put it another way, the governance of human society requires the integration of biophysical, technical, economic, and political aspects alongside psychological, emotional, and affective components (Castoriadis, 1997).

When dealing with the notional side of identity, it is essential to answer questions like: Who are we? Why are we doing what we are doing? How do we know that we are "we"? Hence, this process of autopoiesis is about the ability of the system to define the final causes of its functional compartments within the overall process of self-organization. The emotional endorsement of this side of societal identity is essential to secure the commitment of society's members to express collective action. For example, this notional process of autopoiesis plays an important role in the strong and enduring resistance of Ukraine to the Russian invasion.

When individual members of society dislike what they experience, they react by refusing to accept the identity forced on them by unwanted semiotic controls. As a result, they lose their feeling of belonging and eventually leave the group or stop respecting its rules. As described by Tainter (1988), the collapse of complex societies is unavoidable when the iteration between semiotic control and societal metabolism no longer satisfies the hopes and fears of its members at the lower level. In this situation, information stored in institutional memory loses its original meaning for those operating at the lower level because individuals no longer recognize the associated knowledge as useful. This loss of meaning within the control system progressively translates into an inability to process negative feedback loops. This situation has been described by Funtowicz and Ravetz (1994) as the "*ancien régime* syndrome".

As shown by the collapse of the Soviet Union in 1991, a sudden implosion of a system is not necessarily triggered by conflicts over the truth value of structural knowledge claims (such as the credibility of economic plans decided by a central committee). Collapse can also result from a sudden flip in emotional perceptions regarding the underlying purpose of society. For instance, in the Soviet Union, the established social role of the "border guard" stopped making sense to those working at the gates of the Berlin Wall. This loss of meaning of a specific social practice can spread with a domino effect throughout society. For this reason, the survival of large socio-economic ideologies (e.g., communism and capitalism) depends not only on the technical quality of knowledge claims but also on their capacity to convincingly promise a decent quality of life while minimizing emotional stress. It must preserve the social bonding defined in the process of self-referential autopoiesis.

4. Information disorder

When the recursive alignment between a society's notional representations and its biophysical interactions breaks down, the resulting socio-ecological friction manifests as a profound epistemic crisis. Within an integrated biosemiotic-PNS perspective, this breakdown can be conceptualized as an information disorder. Rather than a simple glitch in technical transmission, this disorder signals a widening structural rift between recorded, institutionalized memory (the "past-present") and the evolving existential aspirations of individuals confronting changing environmental constraints (the "future-present"). Because modern governance relies heavily on institutionalizing a dominant coupling of justification and explanation narratives to maintain legitimacy, it inherently struggles to process negative environmental feedbacks that disrupt its core identity. This section explores the anatomy of this informational gridlock, examining how governance institutions actively filter out disruptive realities to protect prevailing sociotechnical imaginaries, and mapping how these dynamics distort democratic quality control across distinct typologies of misinformation, disinformation, and malinformation.

4.1. Uncomfortable knowledge

As early as 1979, Habermas expressed concern about a systemic legitimation problem in social welfare mass democracies. He argued that modern states, having abandoned prior nationalistic mechanisms of identity formation, tend to base their legitimacy on the idea that all sustainability challenges can be solved via economic progress, thereby keeping structural contradictions and conflicts under control. Today, Habermas's prophecy can be recognized in the European Green Deal, which promises 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 ensuring no person or place is left behind (European Commission, 2021). Facing this tall order, the only operational solution is the reliance on oversimplified and overly optimistic sociotechnical imaginaries, such as the circular bioeconomy and green growth (Giampietro, 2019; Vivien *et al.*, 2019; Giampietro & Funtowicz, 2020; Giampietro & Bukkens, 2022; Giampietro *et al.*, 2025).

In the short term, such imaginaries are effective not only in reducing systemic stress ("yes, we can") but also in transforming complex socio-political issues into mere technical puzzles that can be resolved outside the realm of politics (Funtowicz & Ravetz, 1990; Strassheim & Kettunen, 2014; Winner, 1989; Wynne, 1992). When scientific frameworks stealthily embed these romanticized assumptions or policy-driven "oughts" under the guise of neutral factual reporting, traditional science risks being co-opted into a form of value-imbued advocacy or "normative science" (Lackey, 2025). The confidence of humankind in its ability to fix all problems through a continuous flow of new business models and technical innovations has profound consequences for modern society, driving the systemic selection of policies that prioritize rigid control (e.g., path roadmaps) over flexible, adaptive crisis management.

Rayner (2012) argues that the success of using simplified, optimistic sociotechnical imaginaries in sustainability discourses is not necessarily due to a conspiracy of hidden powers but is an outcome of the sense-making processes employed by institutions. To

make sense of world complexity so they can act, individuals and institutions develop simplified, self-consistent versions of reality. This process requires that knowledge which stands in tension or outright contradiction with these versions must be excluded or expunged; this constitutes "uncomfortable knowledge" (Rayner, 2012).

However, the collective socio-technical imaginary underpinning the European ideal is experiencing a decline in public trust (Benessia *et al.*, 2016; Reinert, 2017). This erosion ultimately threatens the validity of the European Union's social contract, which serves as the foundational guarantee for its stated core values.[1] These comprise achieving sustainable development based on balanced economic growth, price stability, full employment, and environmental protection. Preserving these values depends on a shared belief that existing institutions can guarantee perpetual economic growth alongside social welfare and environmental health. Faced with global polycrisis, growing political disaffection, the collapse of international orders, and resource shortages, society frequently resists a re-discussion of institutional arrangements, locking itself into a stubborn denial of the present predicament. This pushes governing authorities to maintain social cohesion around oversimplified imaginaries to stabilize subsidies and the welfare state. As Gramsci (1992) famously stated: "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".

Can this justify a systemic campaign of policies based on implausible sociotechnical imaginaries—such as green growth through a circular economy (Giampietro, 2019) or rapid zero-emission trajectories through technical innovations (Smil, 2024)? Is the systemic elimination of uncomfortable knowledge from the sustainability discourse compromising the democratic process of quality control in policy choices?

4.2. Misinformation, disinformation, or malinformation

To answer these questions and examine the information disorder in current sustainability discourses, we draw on the work of Hayward (2024) and Wardle and Derakhshan (2017). Wardle and Derakhshan suggest that the phenomenon of information disorder demands careful reflection on language and a critical appraisal of terms. They categorize these phenomena into three distinct classifications:

- *Misinformation:* False information that is shared but not intentionally circulated to cause harm.
- *Disinformation:* False information that is intentionally circulated to cause harm or manipulate outcomes.
- *Malinformation:* Genuine, factually accurate information that, if shared publicly, can cause contextual harm.

[1] See Article 3 of the Consolidated Treaty on European Union.

Building on this framework, Hayward (2024) suggests that analyzing the impacts of implausible sociotechnical imaginaries and the exclusion of uncomfortable knowledge requires combining three analytical approaches:

1. An epistemic approach to check the robustness of a proposition.
2. A behavioral approach designed to detect deliberate strategies for generating false statements to dominate a narrative or establish discourse hegemony.
3. A security strategy deployed to evaluate risks of harm associated with communicating specific propositions, which inherently involves a wicked assessment of what needs to be protected, why, and how.

It is further helpful to consider the distinction proposed by James Carey (1992) between a transmission view of communication and a ritual view of communication. Drawing on this, Wardle and Derakhshan (2017) observe that rather than viewing communication simply as information transmission, we must recognize its role in representing shared beliefs. It operates as a drama portraying contending forces. A ritual view is directed toward the maintenance of society in time through the representation of shared beliefs (Carey, 1992).

The dynamics illustrated in **Figure 3** show that the equilibrium between shared beliefs (imaginaries) and shared representations (daily social practices) must be continuously updated to accommodate new justification narratives (*why*) and explanation narratives (*how*). This iteration implies that interpreting individual experiences must establish priorities over societal concerns for inclusion in institutional justification narratives. Whichever form this prioritization takes, it results in the predominance of a subset of narratives within official storytelling. Explanation narratives used to guide action, conversely, must provide a simplified, self-consistent version of interactions with the outside world. This deliberate or unreflective blending of empirical evidence with subjective benchmarks (such as characterizing an environmental shift as a "degraded ecosystem" rather than a neutral physical state) severely threatens the social license of the scientific enterprise, explaining why public trust in the impartiality of scientists has steadily declined (Lackey, 2025). Uncomfortable knowledge can prevent the achievement of convergence between these two sides of identity. Thus, the formation and adaptation of societal identity relies on an institutional hegemonizing of the chosen coupling of justification and explanation narratives.

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

- Misinformation refers to explanation narratives that are technically unreliable due to the uncertainty naturally inherent in information transmission. Implausible sociotechnical imaginaries frequently fall into this category.
- Disinformation involves a practice designed to unfairly hegemonize a selected narrative for the benefit of a specific group of social actors. Disinformation is

not about polluting technical knowledge claims but about manipulating beliefs within the democratic process to prioritize specific narratives in decision-making, imposing the aspirations of one group over the rest of society.

- Malinformation represents the most complex concept; depending on the context and perspectives involved, a proposition can be deemed dangerous or useful. This category refers directly to the dilemma posed by uncomfortable knowledge.

When do implausible sociotechnical imaginaries and the avoidance of uncomfortable knowledge (such as biophysical limits to growth or the dependence of Western lifestyles on disproportionate resource appropriation) become genuinely harmful? Hayward (2024, p. 17) argues that this occurs if narratives "undermine confidence in the institutions whose epistemic authority a society relies on for its democratic functioning... 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 these cases, uncomfortable knowledge can be described as "toxic truths" (Basham, 2018).

We thus observe a systemic Yin-Yang tension in society between the need to circulate noble lies (rosy sociotechnical imaginaries) to legitimize existing institutions and strengthen the social fabric, and toxic truths (uncomfortable knowledge) to dismantle obsolete myths and enable adaptation. Both noble lies and toxic truths are potentially dangerous, but in different ways. Noble lies stabilize the status quo during periods of equilibrium; however, during a polycrisis requiring urgent structural modification, they generate the *ancien régime* syndrome, defined by Funtowicz and Ravetz (1994) as a state where ruling elites adopt a strategy of denial, refusing to process signals of danger.

In these situations, toxic truths are indispensable for unleashing radical changes in a status quo that is no longer capable of handling crises, even if this causes direct harm to an institutional regime. It is therefore unwise to indiscriminately reject uncomfortable knowledge or label it as malinformation simply because it challenges sustainability policies, as doing so suppresses useful criticism of potentially implausible models used to justify ineffective political decisions (European Environment Agency, 2024).

The quality of political decisions does not depend on their good intentions, but on the fitness for purpose of the narratives chosen to inform policy. As Hayward (2024, p. 19) notes: "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... In a democracy, the terms of acceptance of that justification, if any, should be in the gift of those affected".

Conclusion

Acknowledging that humanity should better adapt to the environment rather than ravage it, the sustainability discussion should not center 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 equilibrium. We must learn how to go through what Funtowicz and Ravetz term the "tragedy of change".

The integration of biosemiotics and post-normal science (PNS) fundamentally improves the quality of the sustainability discourse by replacing the illusion of a singular, optimal scientific "truth" with a participatory assessment of "fitness for purpose". While traditional science reduces complex issues to technical puzzles, a combined biosemiotic-PNS approach forces us to evaluate the complete recursive loop of governance: how societal passions (the *why* / justification narratives) dictate scientific framing (the *how* / explanation narratives), which in turn dictate institutional enforcement (the *what* / normative narratives). By acknowledging that these narratives are impredicatively entangled, this integrated framework provides a diagnostic tool to expose how institutions use oversimplified, growth-centric imaginaries to filter out uncomfortable knowledge and create zones of hypocognition. It improves discourse by shifting the focus from generating more data to auditing the quality, fairness, and relevance of the entire communication process under severe uncertainty.

This integration yields crucial insights for the governance of socio-ecological systems, reviving the core challenge established at the outset of this essay. Viable governance requires stabilizing the resonance between semiotic representations on the notional side and thermodynamic constraints on the tangible side. Because human self-organization relies on a shared group identity and emotional endorsement at the lower level, governance cannot rely strictly on top-down technocratic controls. When semiotic controls ignore environmental feedback and force an unwanted metabolic pattern onto citizens, individual meaning is lost, triggering an *ancien régime* syndrome where rules are no longer respected and the social fabric dissolves. Therefore, adaptive socio-ecological governance must transition away from rigid path roadmaps and path dependency. Instead, it must design institutional architectures capable of deliberately balancing the "Yin-Yang" tension between necessary stabilizing myths (noble lies) and the disruptive, adaptive truths (uncomfortable knowledge) needed to survive structural tipping points.

Ultimately, the widespread perception of global polycrisis indicates that our tangible social practices urgently require change. On the notional side, however, society remains incapable of relinquishing growth-centric imaginaries locked in its collective memory; we face the tragedy of change, but we do not know how to go through it. To resolve this impasse and achieve genuine governance of our sustainability metrics, we must use this combined framework to confront the ultimate political question: what are we willing to lose to preserve what we collectively want to sustain?

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