The quality of scientific advice for policy: Insights from complexity

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Quote as:

Giampietro M (2019), The Quality of Scientific Advice for Policy: Insights from Complexity, Report produced in the context of the Horizon2020 project MAGIC, Grant Agreement No. 689669, 07 May 2019. Available on line: https://magic-nexus.eu/documents/quality-scientific-advice-policy-insights-complexity

Abstract:

This report uses insights from complexity science to analyze the factors affecting the quality of scientific advice for policy. In particular it focuses on biosemiotics—the study of the mechanisms through which life carries out a systemic quality check on the information used for guiding action. Biosemiotics claims that in all living systems the decision-making process is based on purposes, meanings and provisional beliefs to be validated through action. In human societies the implementation of the semiotic process is complexified by the presence of consciousness, passions and reflexivity. That is, when dealing with the sustainability of human societies there are many different concerns/purposes and narratives/beliefs that are relevant for different story-tellers. Trying to consider all of them separately yet simultaneously and prioritizing them is a mission impossible (who should do that and how?). This implies that when looking at the functioning of the semiotic process in human systems we cannot assume that we can use "disenchanted passionless facts" removed from their original semiotic context to guide policy. In policy discussions, "facts" will be contested by default. Policy making should acknowledge that any crisp framing of policy issues entails an unavoidable dose of both *hypocognition*—in relation to the relevant aspects of the problem to be considered—and *hegemonization*—in relation to the choice of a given set of concerns and beliefs. Thus, chosen policy solutions can never be optimal. They are, at best, provisional solutions to reduce the stress experienced by society while fostering the process of learning how to do better in the future. Thus, the usefulness of "scientific evidence" depends on the specificity of each situation, the historical context and the affect associated with current social practices.

Key Words: scientific advice, scientific evidence, biosemiotics, complexity, semiotic process, post-normal science, complex adaptive systems, science for governance

1. Introduction

This paper uses insights found in complexity theory to propose a novel point of view over the factors determining the quality of scientific advice for policy. The text of the paper is divided in two parts.

Part 1 starts with an overview of the basic features of complex adaptive systems relevant for discussing the quality of a process producing and using scientific information for policy. Three relevant points are discussed: (i) the class of complex adaptive systems is composed by becoming systems - they must evolve in time - and therefore they must be anticipatory systems: they must use models to guide their actions. These models must be used to continuously learn and adapt; (ii) complex adaptive systems are organized across different levels and scales. This fact makes impossible to have a deterministic description of their structure and their functioning. We can only generate a deterministic description of a specific aspect or behavior of complex adaptive system after framing it within a given epistemic box – i.e. by adopting the strategy of reductionism in which the aspects considered as relevant are represented within a given descriptive domain (associated with a pre-analytical choice of a relevant dimension and a scale of analysis); (iii) biosemiotics can be used to identify the basic mechanism developed by life to anticipate, learn and adapt when checking the validity of the information used to guide action. This implies that the decision-making process of complex adaptive systems is based on purposes, meanings and provisional beliefs to be validated through action. These points are illustrated with practical examples.

Part 2 uses the concepts illustrated in Part 1 to analyze the special challenges found when implementation a semiotic process in human societies: additional inputs to the process - consciousness, passions and reflexivity – make more difficult to "validate" both the selection of concerns and believes used to guide action. In relation to this point it is important to stress the difference between "facts" (validated information inside a given epistemic box – related to beliefs) and "concerns" (the perception of a threat or an aspiration requiring action – related to purposes). Because of these differences human systems cannot check the quality of the information used for policy by relying on representations developed within a single epistemic box (reductionism). In turn this requires understanding the difference between "scientific narratives" (a given explanation of causal relations inside a given epistemic box) and "story-telling" (a meaningful choice of an action/policy effective for dealing with a given problem which is associated with the endorsement of one or many epistemic boxes). This difference entails considering that the choice of a scientific explanation ultimately depends on a pre-analytical choice of a concern – i.e. the priority given to a specific problem to be solved. From this perspective, the semiotic process in a society (the institutional organization of the process of autopoiesis) represents a heuristic solution capable of learning (by doing) how to handle simultaneously non-equivalent but legitimate concerns, while exploring an expanding the set of purposes (meanings), beliefs, and controls found in the society across scales and dimensions of analysis. This expansion of concerns, purposes, beliefs, implies also expanding the number of epistemic boxes that should be used for representation in the system of control.

In conclusion we can say that the semiotic processes in human societies requires four components: (i) *the political process defining the identity of the system,* determining the priorities over the various concerns, purposes and beliefs expressed in the society; (ii) *governance*, providing the interpretations of the information used to guide action when addressing different concerns; (iii) *scientific inquiry* providing a repertoire of representations (narratives, models, explanations) needed to guide action; and (iv) *social practices* (the action) required to provide the feed-back determined by the pragmatic step – the lesson learned from the experience done when applying the policy. The quality of the process of production and use of scientific advice for governance depends on the proper interaction of these four components.

2. The insights from complexity about the quality of scientific advice

2.1 Complexity is not a new emerging field . . .

The field generically called "complexity theory" is often considered as a new emerging field in the academic discourse. However, it should be noted that several important theoretical contributions to this field are quite old – i.e. general systems theory (Von Bertalanffy, 1950), cybernetics (Ashby, 1956), relational analysis (Rashevsky, 1954; Rosen, 1977), biosemiotics (von Uexküll, 1957(1992)), non-equilibrium thermodynamics (Schrödinger, 1944 (1967); Prigogine, 1978; Prigogine and Stengers, 1984), hierarchy theory (Simon, 1962; Koestler, 1968; Pattee, 1973; Salthe, 1985), theoretical ecology (Margalef, 1968; Odum, 1971, Ulanowicz, 1986), energetics (Lotka, 1922; Zipf, 1941, Cottrell, 1955), autopoiesis (Maturana and Varela, 1980). The perception that "complexity" is a new emerging field can be explained by the systemic neglecting of these contributions in the development of modern economic narratives, that have hegemonized the structuring of the process of decision making in the modern era. The growing interest for this "emerging field" seems to indicate that issue of sustainability is forcing to re-consider the shortcoming of reductionism in order to be able to check the quality of the scientific inputs used to inform policy (Giampietro, 2018).

Probably the field of *scientific advice* is where new insights from complexity are more needed. In fact, in a modern complex society it is not even clear "who" is giving advice to "whom". Are we dealing with individual advisors? - specific instances of experts - or with equivalence classes of advisors? - classes of scientists (that must be organized in some way) sharing the same opinions. Are we dealing with a given type of institution? - the EU commission - or a specific instance of it? - the incumbents officers playing their institutional roles in the selected type of institution at a given point in time, within a given political process. These questions focusing on the distinction between "instances" and "types" may appear as examples of "sophist specious reasoning" to the general public. However, considering the difference between "expected social roles" and "what the incumbents do in these roles" may be an essential preliminary step for analyzing the quality of a decision-making process – e.g. to assess the influence of organized lobbies and the integrity of the instances expressing the expected roles.

2.2 The common problem of sustainability shared by all self-organizing systems

The most elementary class of self-organizing systems is represented by dissipative systems (Schrödinger, 1944; Glansdorff and Prigogine 1971; Nicolis and Prigogine 1977). All the members of this class are open systems affected by an existential predicament: they can express their own identity making them entities distinct from their context (e.g. a tornado or a whirlpool). However: (i) their identity is totally defined by the availability of favorable boundary conditions; and (ii) their identity depends on (and damages) the favorable conditions provided to them by the context. Within the class of dissipative systems, we find the class of complex adaptive systems (Gell-Mann, 1994; Holland, 1999), a more developed form of self-organizing systems. The identity of these systems is determined by an autopoietic process (they use their own information to make themselves - Maturana and Varela, 1980) – i.e. they are organized by "informed autocatalytic loop" (Odum, 1971) or they "send messages to themselves in the future" (Margalef, 1968). However, also for this class, the possibility of expressing their dissipative pattern depends on the existence of an admissible environment (Odum, 1983; Rosen, 1985; Ulanowicz, 1986). In fact, the identity of any type of *open systems* can only be preserved by gathering and consuming useful inputs gathered from the context and disposing of useless waste into it: their forced metabolism entails a continuous damage to the admissible environment they depend on. For this reason, they must be: (i) "becoming systems" (Prigogine, 1978), because expanding just by doing "more of the same" will lead sooner or later to sustainability troubles; and (ii) "anticipatory systems" (Rosen, 1985): in order to be able to adapt in time, they have to be capable of predicting problems that can jeopardize their existence and of adjusting to new situations. The class of complex adaptive systems includes a variety of systems from amoebas and ecosystems to arrive to cities and modern societies (Brooks et al. 1988; Dyke 1988; Smith et al. 1988; Giampietro et al. 2012; Odum, 1971; Schilling and Straussfogel 2008; Wolman, 1965). The need of anticipation is particularly important when considering the sustainability of modern economies. In fact, a quick economic growth implies a continuous expansion of the activities of the metabolic pattern associated with a continuous enlargement of the economic process both in terms of the size of the metabolic system (population, technologies and infrastructures) and in terms of the pace of activity per unit of size (the pace and density of flows of resources consumed per capita). A massive expansion of the economic activity in a finite planet, when considered from a biophysical perspective, clearly suggests that the most important features of scientific advice for sustainability should be that of anticipation (Poli 2017). This is where we can identify a serious problem with the current use of science in sustainability: anticipation implies "self-referentiality" (Emmeche, 1997). An agent that wants to gain anticipation about the effects of its actions must adopt models describing its own interaction with the external world. *This implies that a representation of the agent (associated with its identity) must be included in what is modelled*. Unfortunately, scientific advice tends to be based on reductionism, that implies a systemic neglect of the role of the observer in defining what is observed (Allen and Starr, 1986): the observations of the world adopted to generate scientific evidence are done "from the outside". This generate a long list of unanswered questions: Who is observing? Why? At which scale? What are the implications of the chosen scale and dimensions of analysis? Why is this observation relevant? The systemic adoption of this scientific paradigm entails that modern science is focused on how to fix the "external world" – i.e. the dream of prediction and control - that is described as "wrong" because it does not match perfectly human wants. Very rarely science is used to study how the society should change its wants for becoming compatible with its context.

2.3 Biosemiotics

Semiosis literally means the production of signs, and semiotics is usually referred to as the study of signs. The pioneer of this field, Peirce (1935), has suggested the concept of semiotic process as an endless cycle in which *signs* (produced in the step REPRESENT) are used by *interpreters* (in the step TRANSDUCE) to guide the action of *agents* (in the step APPLY) whose results are then used by *interpreters* (in the step TRANSDUCE) to improve the quality of the original representation based on *signs* (in the step REPRESENT) in order to be able to go for another cycle of action. Therefore, the basic steps used to check the quality of the information used in the autopoietic process of human societies.

→ (syntax) represent → (semantic) transduce → (pragmatic) apply → (semantic) transduce →

Biosemiotics is the scientific field that studies the modalities and the role of signification in living systems flagging the fact that the production and use of information is an essential component of life. Von Uexküll (1957) used the concepts of Peirce about semiotic to suggest that animals are *interpreters* of their own environment. For an exhaustive overview of the field see Kull (1999). According to Barbieri (2014) there are two types of biosemiotics: (i) one is based on the original idea of Von Uexküll and developed by Sebeok (1972) – supported by the International Society for Biosemiotic Studies – ISBS - focusing more on the role of animal interpretation; (ii) a second, more recently established – supported by the International Society of Code Biology - ISCB – focusing more on the key role of *codepoiesis* in the generation of new meanings and in the preservation of them in living systems. In this second branch, life uses codes for finding and preserving new meanings by integrating them in networks of interactions. Margalef (1968) a pioneer of theoretical ecology suggested that living systems send messages to their own future generations providing insights on how to survive and reproduce.

An important observation about the required combination of the various steps of the semiotic process is that we have to admit the existence of non-material "entities" that can only be handled in a complex representation. That is, signs can be seen as material realizations but signs become relevant in the semiotic process only because of their meaning (a non-material entity) for the interpretant. "*As living beings, we have a built-in drive to make sense of the world, to give meanings to things, and when we give a meaning to something, that something becomes a sign for us. Sign and meaning, in other words, cannot be taken apart because they are the two sides of the same coin. Semiotics, therefore, is not just the study of signs; it is the study of signs and meanings together. The result is that a system of signs, i.e., a semiotic system, is always made of at least two distinct worlds: a world of entities that we call signs, and a world of entities that represent their meanings*" (Barbieri, 2014).

This point is important because it entails the existence of relevant "immaterial observables" – e.g. the meaning of the sign, or the purpose of an action - to be considered when checking the quality of a semiotic process. In relation to this point it should be noted that reductionism is not well equipped to observe immaterial observables and their relations. On the contrary, complexity theory (as discussed in Section 3) acknowledge the need of describing material and immaterial observables. "*A human activity system can be defined as 'notional system' (i.e. not existing in any tangible form) where human beings are undertaking some activities that achieve some purpose*" (Patching 1990). Notional systems can be realized in their material representation (e.g. recorded in the system of control such as sequences of DNA in genes or coded information in a software), but still their essence is immaterial (Giampietro et al. 2005).

In conclusion, biosemiotics shows that concepts like purposes, beliefs, meanings, can be used to get procedural definition of what should be considered as the "truth" (in a specific situation) and therefore can be considered as basic components of the decision-making process of all living systems. It is important to note that these concepts do exist also outside the human realm where there is no consciousness and reflexivity. Howard Pattee (1995) suggests that the ability of establishing an operational definition of these concepts within an autopoietic process represents the essence of life: *"Metaphorically, life is matter with meaning. Less metaphorically, "semiotic complexes" are material structures with memory by virtue of which they construct, control and adapt to their environment"*. But when consciousness is not present how can living systems check the quality of their purposes and beliefs? Biosemiotics is important exactly because it allows to identify the basic mechanism required to check the quality of information used as input to guide action avoiding the complications entailed by passions and reflexivity.

Pattee (1995) suggests to combine biosemiotics and cybernetics for explaining the mechanism of learning of complex adaptive systems capable of guaranteeing their own maintenance, reproduction and adaptation: "*In autopoietic metabolic systems the mechanism of entropy generation is determined by semiotic controls defining constraints reflecting the effect of adjustable rules and not of inexorable laws*". As explained below, the difference between adjustable and inexorable laws is essential. This is also a point made about codepoiesis by Barbieri, 2014.

According to Pattee, in order to be able to learn how to develop better anticipation, the system must have:

1. *a purpose* associated with its own identity (path dependency). The existence of a purpose is needed in order to be able to compare *expected result* against *achieved result* – i.e. in this way it becomes possible to interpret the feed-back from the external world to check the validity of the information used to achieve the purpose;
2. *a belief* associated with the meaning associated with recorded knowledge. This belief reflects the expectation that, in a given situation, when operating the system of control according to the given information it will be possible to achieve the specific goal.
3. *a system of control with contingency*. Here the difference between physical laws and semiotic controls becomes essential. Using the example given by Pattee, the behavior of a flame is determined by the characteristics of an attractor which is regulated by physical laws. "*A flame cannot learn how to behave in a different way: it is a simple dissipative system fully determined by its boundary conditions. On the contrary the behavior of a given organism is determined by both the characteristics of its structural organization and its semiotic controls, both of them can be adjusted*" Giampietro, 2018;
4. *the ultimate validation through action* – the closure of the semiotic process can only be obtained by testing the beliefs in real action. This requires that actual instances (material observables in physical systems) of the types described in the information (immaterial observables in notional systems) test the validity of the given combination of immaterial aspects (purpose, beliefs and controls) in the material interaction with the external world (results of the guided action).

2. Biosemiotics: purposes, beliefs, meanings, and "truth" outside the human realm

2.3 The epistemic box used to validate beliefs and control in non-conscious living systems

Note that changes in semiotic controls can refer to a change in: (i) the type of signals used to observe the world (how to observe what is observed and the associated representation); (ii) the structural organization of the agent (the possible behaviors associated with the scale of operation) related to the characteristics of the admissible environment (i.e. if the organism is living in the water or on land); and (iii) the characteristics of anticipatory models generating the information used for control (very simple or sophisticated). The example illustrated in Fig. 1 shows a simple anticipatory model used by a cockroach. In this example: (i) the purpose is to survive; (ii) the belief could be "light equals danger" entailing a normative narrative (system of control) “if there is light, then run for darkness”. This simple anticipatory model, coupling a “belief” to a “system of control”, may be applied to different structural types of insects (e.g. cockroaches, silver fishes, and earwigs): (i) expressing their behavior at the a scale (spatio-temporal domain) similar to that of the cockroach; and (ii) using a similar “dimension of analysis” (typology of sign – light vs darkness). It should be noted that this specific coupling of purpose and belief (the story-telling of the cockroach used to guide action) would result useless to guide the action of animals living in the darkness.

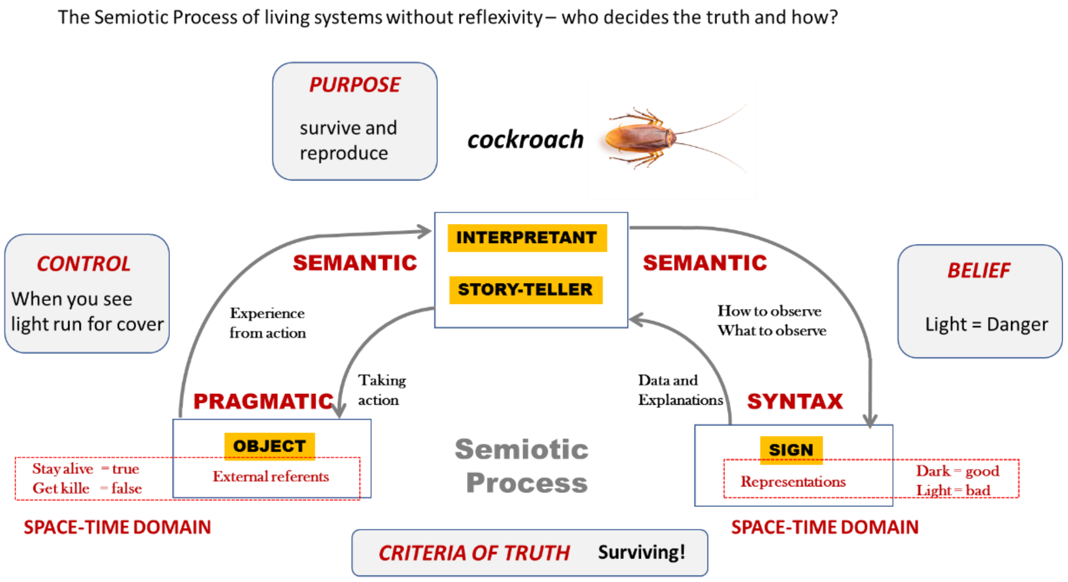

Fig. 1 The semiotic process in the life of a cockroach

Two important points should be made here. In this example, the instance of cockroach is at the same time the observer (producing the input used to implement the belief), the interpreter (matching the input of information with the required action) and the agent (operating the system of control). This implies that the representation used to guide action and the perception of the external world belong to the same descriptive domain (Giampietro et al. 2005). This anticipatory model would not be effective if it would be adopted by a virus or an amoeba living inside a dog. On the contrary, neither the purpose of surviving and reproducing nor the validation of the information associated with the criterion of truth (whether the instance of cockroach survives or not) are generated and decided by the instance of cockroach. The identity and the system of control are given to the instance of cockroach by the outside. An instance of cockroach is just testing the information received from its gene pool about the admissibility of the environment. An instance of cockroach cannot learn how to improve and adapt its beliefs. This means that the learning and the adapting of the identity of the species is done at a higher hierarchical level than that of the individual organism – where the species is generating mutual information interacting with other species within ecosystems and building genetic taxonomies (Giampietro, 1994).

This simplified representation of the decision space of an instance of cockroach can be used to identify and define the epistemic box used by it. In Fig. 2 we apply the concept of triple-loop learning to the analysis of the semiotic process indicated in Fig. 1. It should be noted again that the “learning” is done by the gene pool of the species and not by the instance - the instance can only survive or die! Depending on the modifications determined by the amplification of successful genetic information and the elimination of unsuccessful genetic information the species can change the design of the control (single loop – e.g. add more attributes to identify potential danger) or improve the system of control (double loop - changing the structural characteristics of the cockroach). In this case, these are adjustments that still preserve the correspondence of the typology of observer and typology of agent. However, the functional definition of the cockroach (the "purpose" of its existence so to speak) or better the meaning/role played by the species in its ecosystem (why cockroaches make sense as components of the ecosystem) can only be obtained at a higher level of analysis. A change in the purpose of a given population of cockroaches coincides with a change in the definition of the niche of that species in its ecosystem. At this level, when discussing the role of the network niche, the information associated with local beliefs and local systems of controls operated by instances of cockroaches becomes no longer relevant.

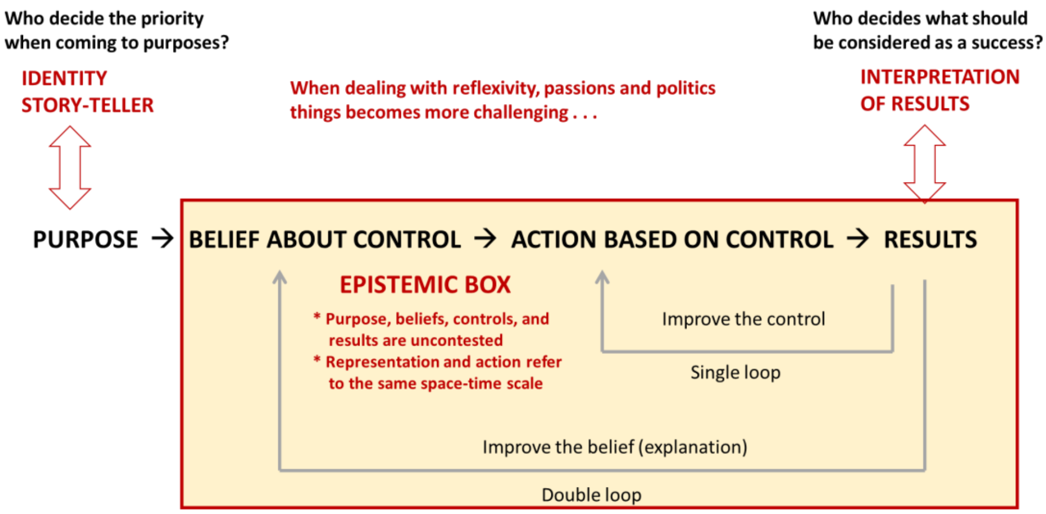

Fig. 2 The triple loop learning crosses the divide instance/species

This analysis of the learning of species can be used to define the concept of epistemic box. An epistemic box is the specific combination of beliefs, narratives, observations and models that at a given scale can be used to organize information (perceptions and representations) to provide a useful representation of a relation of causality. The identification of an epistemic box is required to validate a given combination of a narrative (perception) and a given model developed in a descriptive domain (representation) that may result useful to guide action in relation to a specific purpose. We will come back to this definition in Section 4.

3. The epistemological predicament associated with complexity

3.1 The co-existence of measurable facts and non-measurable facts in the external world

Several interpretations of the concept of complexity point at its epistemological dimension: a complex phenomenon is a phenomenon which require the simultaneous perception and representation of its relevant aspects by combining several non-equivalent narratives, dimensions and scales of analysis (Simon, 1962, 1976; Rosen, 1977, 2000; Salthe, 1985; Ahl and

Allen, 1996; O'Connor *et al.*, 1996; Funtowicz *et al.*, 1998; Allen *et al.*, 2001; Giampietro, 2003; Giampietro *et al.* 2006).

3.1.1 An example of epistemological troubles taken from fractal geometry

An empirical measurement of a length of a material object is often considered as the ultimate example of a fact. However, in a seminal paper entitled "How Long Is the Coast of Britain? Statistical Self-Similarity and Fractional Dimension" Benoit Mandelbrot have shown that the measurement of a fractal object (an object that can be observed across different scales) will not generate uncontested facts. That is when dealing with a complex object – i.e. a coastline – you can only measure "what you have declared that the object is" in a given descriptive domain. That is, you have to define an identity of the object to be measured, associated with the representation of the coast-line. This definition requires the choice of the dx used in the representation of your perception. An example of this point is given in Fig. 3.

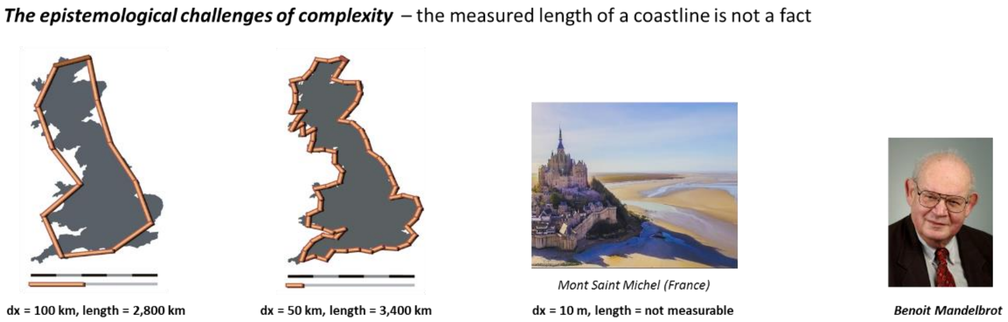

Fig. 3 Non-equivalent descriptive domains, non-reducible models and the arbitrariness of facts

For a person walking on a given tract of coast, whenever tides do not entail important effect on the chosen trajectory, the length of a given tract of coastline can be considered as a fact. However, for a captain of a large oil tanker forced to travel at a certain distance from the coast when using nautical maps will find a different fact when reading the length of the coastline (including that beach). Another bifurcation of "the measured length" will be experiences by a truck driver looking at the information from her GPS navigation system. As mentioned in the paper of Mandelbrot, the statistical offices of France and Belgium give different assessments (measured in km) of "the same border line" – i.e. the tract of border they share - simply because they represent it in non-equivalent ways in their maps. In general, we can expect that the assessment of the tract of border in common between two countries of different size will be shorter in the larger country and longer in the smaller country because of the use of maps of different scales.

3.1.2 Examples of epistemological troubles taken from hierarchy theory

Another systemic cause of degeneration of quantitative mappings (one to many and many to one) is associated with the concept of holon (Koestler, 1968; 1978) that can be analyzed in conceptual terms both using ***hierarchy theory*** (Allen and Starr, 1982; Ahl and Allen, 1996) and ***relational analysis*** (Rashevsky 1954; Rosen 1977, 1985; Louie, 2009, 2013). Hierarchy theory can be defined as ''*a theory of the observer's role in any formal study of complex systems''* (Ahl and Allen, 1996 p. 29). Relation analysis studies the existence of expected patterns of relations over the structural and functional elements of complex adaptive systems that can be abstracted away from the special characteristics of their material components. These two perspectives are important because the complex organization of living systems organized through semiotic activity implies a systematic blurring of the distinction between physical and semiotic activity. When observing the operation of complex adaptive systems, it becomes almost impossible to fully separate the observation of organized structures from the expression of relational functions (Simon, 1962). When observing human institutions, the characteristics of the behavior of incumbents are muddled with the characteristics of the social roles (Bailey, 1990). In the same way, any description of events tends to confuse types with individual realizations of types (Salthe, 1985). A very short overview of the epistemic challenges determined by both the nature of complex adaptive systems and the nature of the mechanism used by human to perceive and represent events in the external world, is illustrated in Fig. 4 (for a more detailed discussion see Giampietro and Allen, 2006).

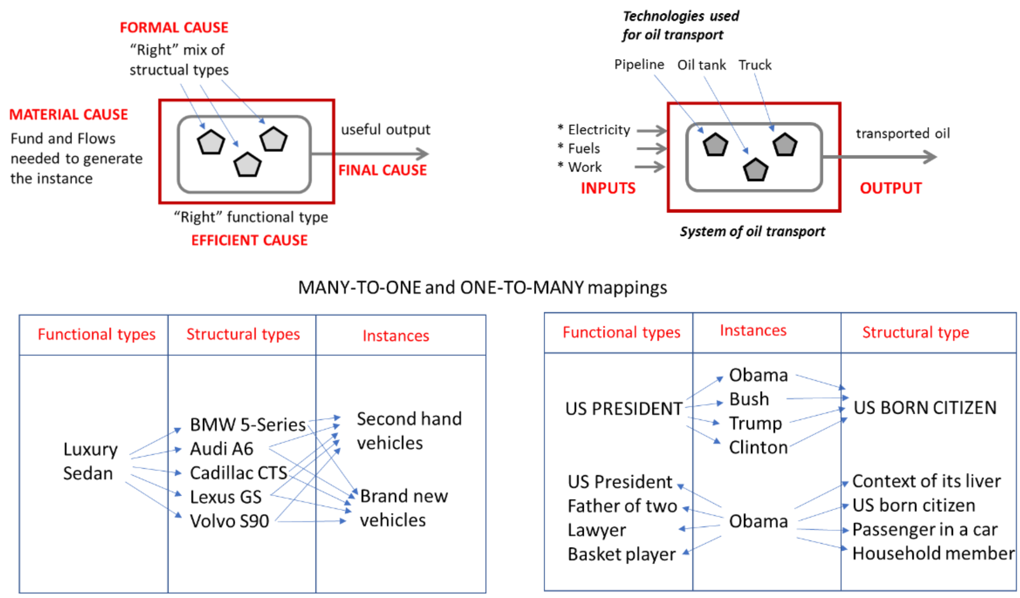

Fig. 4 Emergent properties and the impossible quantification of the characteristics of holons

Let's explain in detail, the elements of Fig. 4.

**** on the upper part*** - we can see how the four Aristotelian causes (a framing suggested by relational analysis) can be used to identify the relevant elements to observe and study. The heuristic epistemic tool combining together the efficient cause (the functional element) and the typology associated with the formal cause (the structural element) has been called "*holon*" by Koestler (1968). It is used to make sense of what is observed when gathering and organizing information for analysis. The conceptual representation of the components of a holons are shown on the left. A practical example of application of the analysis based on the concept of the holon is provided on the right, referring to study of the performance of the activity "oil transport". The four causes enter into play here: (i) we are studying this activity because is relevant (it is a useful function): it reflects a final cause; (ii) this activity can only be expressed by a functional complex - a functional type guaranteeing the expression of a set of functional relations: it is guaranteed by an efficient cause; (iii) to be reproduced and adapted in time this activity must be associated with a recorded type of information that makes it possible the reproducibility of the structural components of the efficient cause – the blue-prints of the various structural types used in expressing the function: it depends on the existence of a formal cause; (iv) there are material elements (fund elements – what remain the same - and flow elements – what is consumed in the process) required to express the activity. In this combination we find the unavoidable co-existence of notional elements (final cause, efficient cause and formal cause) and material elements: the material factors associated with the material cause.

**** on the lower part*** - we can appreciate the systemic degeneration of mapping over the components of the holon: (i) a functional type; (ii) a structural type; and (iii) an instance of the combination of the two types. In the example given in the bottom-left box, we can see the confusing effect of this relations. The ex-US President Obama used to be a "holon", when he was at the same time: (i) an instance of a given structural type – i.e. a US citizen born in the US, (a normative requirement to become US president); and (ii) an instance of a given functional type – i.e. an elected US president. However, a holon (something that can be observed and described both in material and immaterial terms) as a combination of functional types, structural types and instances is elusive when coming to measuring and modelling. The weight of the holon "US President" is different depending on the instance considered (e.g. Trump vs Obama). In the same way, the same instance – Mr. Obama – can belong simultaneously to different functional types – e.g. a father, a basket player – and structural types – e.g. a passenger in a car, a human body. This predicament applies also to technical assessments. For example, the performance of oil transport in a country does not depend only on the performance of the technology used – i.e. the technical coefficients of pipelines, oil tanks and trucks - but also on the specific mix of their use (and many other factors, such as utilization factors, age of the instances of technologies). When coming to scientific advice the curse of the duality between "types" and "instances" can be fully appreciated looking at the lower left box showing another family of examples of many-to-one relation. When buying a car, an expert can easily provide advice about the expected characteristics of a given car models – e.g. BMW 5-Series, Cadillac CTS - according to available information. However, when buying a second-hand vehicle (a specific instance of a known type) there is another ingredient that is essential to make robust the advice. In addition to the available information about the characteristics of the car model we need additional information about the special history of the vehicle. In this situation, trust in the information about the instance (e.g. given by the owner) can become even more important than an exhaustive comparison of the performance of the different models of cars given by the experts on internet.

3.2. Explanations (narratives) are neither right or wrong, but they may be useful or useless

In this section we provide a simple example illustrating the factors determining the "usefulness" of an explanation of a given event. The event to be explained is the death of a given person and four different explanations are given for this event. In addition, we provide four possible "users" of this explanation operating in different context. An overview of this information is given in Fig. 5 in which we have: (i) on the left, in the first column a list of the four narratives and the context in which they are proposed; and (ii) on the right, two columns in which different story-tellers (those that should endorse and use the proposed explanation) are coupled with each one of the explanation.

The figure shows that depending on the combination of: (i) narratives; (ii) contextualization; and (iii) story-tellers none of the explanations provide any useful insight for guiding action, when considering the first column of story-tellers. On the contrary, in the second column all the chosen narratives do provide useful information for the purposes of the story-tellers.

WHAT IS A GOOD EXPLANATION? NARRATIVES (explanations of events) ARE NEITHER TRUE OR WRONG

NARRATIVE	Story-Teller	Story-Teller
EXPLANATION 1 --> "no oxygen supply in the brain" *Space-time scale*: VERY SMALL *Example*: EMERGENCY ROOM	Tax expert	Doctor in the emergency room
EXPLANATION 2 --> "affected by lung cancer" *Space-time scale*: SMALL *Example*: MEDICAL TREATMENT	Philosopher	Pharmaceutical researcher
EXPLANATION 3 --> "individual is a heavy smoker" *Space-time scale*: MEDIUM *Example*: MEETING AT HEALTH MINISTRY	Doctor in the emergency room	Tax expert
EXPLANATION 4 --> "humans must die" *Space-time scale*: VERY LARGE *Example*: SUSTAINABILITY ISSUES	Pharmaceutical researcher	Philosopher

Fig. 5 Non-equivalent narratives about the death of a person

3.3 The usefulness of scientific advice depends on the identity of the story-teller

An example similar to the previous one is provided in Fig. 6. This time, rather than a list of explanations of events, we have a list of story-tellers – i.e. scientific experts - providing advice on how to achieve an expected result. It should be noted that the content of Fig. 6 (the list of contrasting advices of experts) has not been made-up with the goal of providing a theoretical example. This list reflects the actual content of talks given at a real conference by different experts (the first author was among the participants of the conference and had the opportunity of recording it).

The contrasting advices provided by the invited experts are referring to three different policy domains (national policy, international policy, gender issue). All these advices were given by reputable scientists and supported by convincing evidence. Still a quick overview of the content of Fig. 6 identify a clear systemic problem: depending on the problem one wants to solve (e.g. protecting the nutrition of the urban poor vs helping the economic activity of poor farmers) a pertinent advice can be legitimately in contrast with another pertinent advice. In relation to this point we can only observe that the purpose of the policy (the choice of the problem to be solved) can be associated with the "identity" of the story-teller (its cultural context) determining the priority of the concern to be addressed.

For example, all the story-tellers coming from the developed countries suggested policies having the goal of stabilizing the status-quo (that they like), whereas all those coming from developing countries suggested policies having the goal of changing the status-quo (that they do not like). If we accept this point, then we have to admit the quality of the choice of a policy advice cannot be analyzed only in scientific terms . . .

Fig. 6 The contrasting scientific advice of different experts/story-tellers

4. The semiotic process in human societies and the role of scientific evidence

4.1 The role of the semiotic process in human societies

According to what discussed so far, we can make two points: (i) the identification and prioritization of concerns is carried out by story-tellers; and (ii) facts can only be obtained after having identified an epistemic box relevant for addressing a given concern. This entails that the pre-analytical selection of an epistemic box is required in order to check the quality of a representation associated with a given narrative – i.e. scientific evidence.

It is important to elaborate on the key difference between the characteristics of the semiotic process taking place in human systems and the semiotic process taking place in biological systems where there is no consciousness and reflexivity. The decision-making process of instances of cockroaches (discussed in relation to Fig. 1) is based on the adoption of just one epistemic box that is given to it by default (with its genes). The story-teller of the semiotic process is outside the domain of activity of the instance testing the validity of purpose, beliefs and systems of control. This implies that the death of the instances is one of the natural outcomes, which is entailed by the process of learning. An instance of a cockroach, when considered in isolation from the ecological role it plays, should be considered just as a "cyborg": a biological machine getting its identity (purposes, beliefs and controls) from the outside.

In human societies things are radically different. There are several levels expressing story-telling – i.e. path dependency reflected in the definition of identities to be preserved – the cultural level, the societal level, the community level, the household level, the individual level. At all these levels we can find a variety of non-equivalent identities (purposes, beliefs, systems of control) referring to different biophysical processes observable and representable only across different dimensions and scales. Different non-equivalent story-tellers, observers, agents interact using a large variety of narratives (associated with the adoption of a large variety of epistemic boxes) in order to learn and adapt. Each one of them has different concerns and different priorities. An overview of the process of compression of "concerns" into "facts" to be used as useful input to guide action taking place in society is illustrated in Fig. 7. This representation reflects the conceptualization provided by Checkland and others (Checkland, 1981; Checkland and Scholes, 1990; Röling and Wagemakers, 1998) under the name of Soft-System Methodologies. "*We have a situation in everyday life which is regarded by at least one person as problematical. There is a feeling that this situation should be managed to bring about "improvement". The whats and the hows of the improvement will all need attention, as will consideration of through whose eyes "improvement" is to be judged. The situation itself, being a part of human affairs, will be a product of a particular history, a history of which there will always be more than one account*". Checkland and Scholes, 1990 p. 28

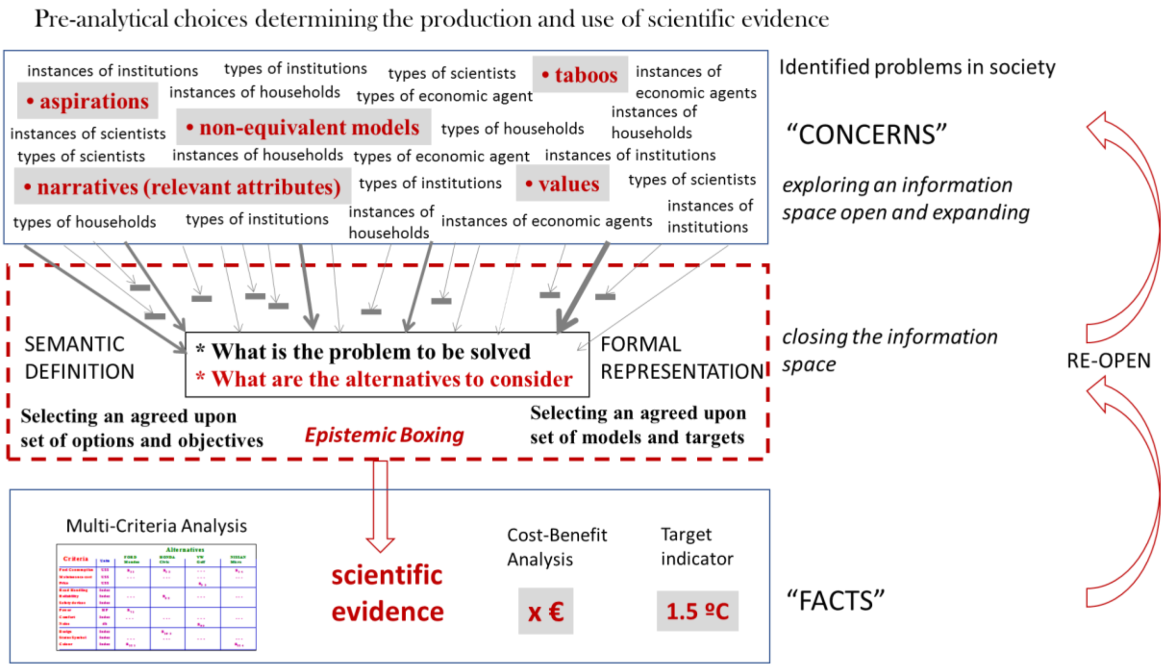

Fig. 7 The "compression impossible" of a semantically open and expanding sets of framings of non-equivalent concerns into a formal representation of shared facts

On the top we can observe a variety of typologies and instances of story-tellers (households, economic agents, other institutions) that are continuously checking their *anticipations* against their *expectations* in order to identify and prioritize concerns. Because of the variety of histories, aspirations, narratives, the adoption of non-equivalent anticipatory models, values, fears and taboos found in the universe of social practices, the information space associated with these concerns is virtually infinite and expanding. However, in order to be able to carry out a validation of knowledge claims allegedly useful to address specific problems it is necessary to generate first of all a formal definition a problem that allows the evaluation of a set of alternative actions. Put in another way, in order to be able to discuss the most appropriated of formalizing a problem (a task for the scientific inquiry) we have "box it" within a given semantic framing. However, this epistemic boxing would be required by all the concerns found in society – a mission impossible. Therefore, the selection of a limited set of shared epistemic boxes, to be used as input by scientific inquiry, reflects the existence of a filter over the flow over the virtual infinite set of concerns found in society. That is, "knowledge claims" are the result of a two-step process: (i) validation of the problem framing at the societal level; (ii) formalization and use of the framing as the object of scientific analysis. Scientific evidence refers only to knowledge claims. To due the existence of power asymmetry in both the instances and the institutional roles that control the process of epistemic boxing it is impossible to avoid that the "compression impossible" of an infinite universe of concerns into a finite and limited set of relevant facts used to inform action (Fig. 7) will result in the hegemonization of just a limited set of perspectives reflecting the existence of specific agendas. The better organized groups of power will have the opportunity of "hegemonize" the story-telling endorsed by the society. In relation to this point, Checkland and Scholes (1990) suggest that the process of compressions and filtering should be iterated in time allowing the re-opening of the discussion after learning about the implications of relevant concerns neglected in the previous round. An iterative procedure based on a series of enlargement and compression of the information space has been also suggested by Allen and Hoekstra, (1992) and by Stirling (2007) under the expression "opening up" and "closing down" the discussion space.

4.2 The priority to be given to problems to be solved cannot be "scientifically proved".

If we accept this analysis of the "messy" situation experienced by those living "inside" the semiotic process in human societies, we can reflect on the limits of the role that scientific inquiry can play in determining the priorities over concerns to be addressed. Before discussing this issue, let's introducing the theory of modeling relation proposed by Robert Rosen (illustrated on the left side of Fig. 8) looking at the foundation of quantitative analysis.

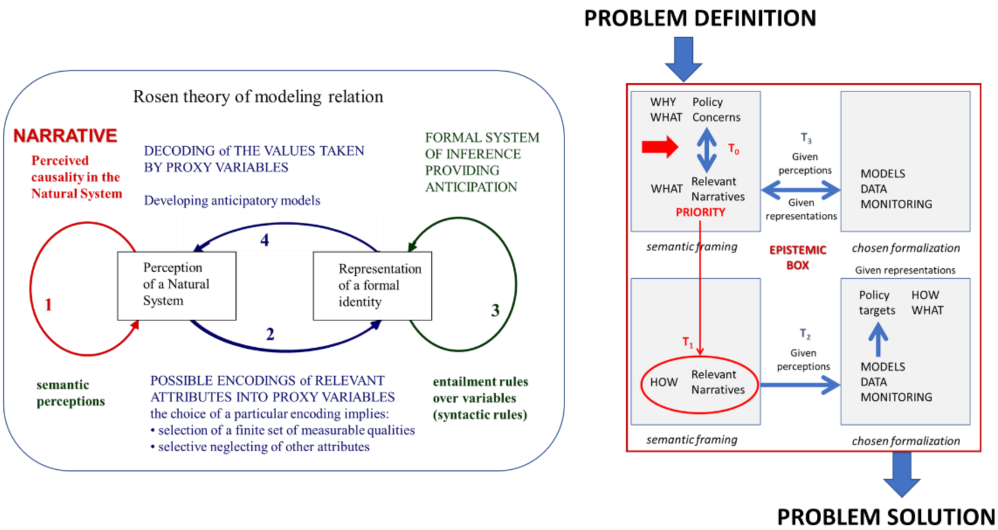

Fig. 8 Rosen modelling relations and the relation between problem definition and solution

Rosen defines a "complex system" as one which allows us to discern many perceptions of it (1977). Depending on the selected narrative about the relevant events to be studied (a given perception of causality – illustrated by the arrow #1), the resulting perception of the natural system to be modeled can be represented after selecting a set of relevant attributes, whose observations are encoded in proxy variable (illustrated by the arrow #2). At this point the representation consists of a formal identity of the system (a state described by the value taken by the chosen proxy variable) to which it is possible to apply a formal system of inference (illustrated by the arrow #3). This system of inference can be used to simulate the expected changes in the perceived system by looking at the changes of the values taken by the proxy variables - through the arrow #4.

Put in another way, the modeling relation illustrated on the left side of Fig. 8 represents the chosen epistemic box for establishing a relation between a given perception of causality in the natural system (arrow #1 - in relation to the pre-analytical choice of attributes) and a representation of causality (arrow #3) based on a pre-analytical choice of a scale and a dimension of analysis (arrow #2). After establishing this set of relations, we can say that the "scientific model" is validated when the various arrows included in the loop #2, #3 and #4 will coincide with the perception of causality described in the loop #1. For more details see Giampietro et al. 2006; Mayumi and Giampietro, 2006. At this point this epistemic boxing of a perception of causality can be used to develop anticipatory models through an operation of decoding. Changing the value in the arrows #3 it is possible to make inference (through the arrow #4) on expected changes in the actual perception according to the predictions of the model.

The right side of Fig. 8 shows the temporal series of choice determining the formation of an epistemic box. First, the problem definition is obtained by coupling a given concern with a narrative. Then this narrative is used to select a modeling relation establishing the set of relations over the arrows (#1 <-> #2, #3, #4). Finally, the development of pertinent models that are validated through empirical analysis makes it possible to indicate possible solutions to the original problem.

When considering this process, can the scientific evidence developed within this epistemic box be used to evaluate the priority to be given to different concerns? According to what discussed so far, the selection of models and data (*the chosen quantitative representations used to generate "scientific evidence"*) is a by-product of the original choice of a relevant concern. That is, the choice of story-telling entails selecting just one of the possible narratives relevant for the issue, a choice translating into selecting just one of the possible scales and dimensions of analysis. That is, the pre-analytical choice of framing determines a lock-in of the scientific evidence into the given "epistemic box" generating a tautological relation between: (i) definition of indicators to monitor success; and (ii) definition of policy targets to be used to implement policy. The issue of how to prioritize these targets in relation to other possible targets referring to other policy concerns cannot be addressed using this scientific evidence. The priority over non-equivalent concerns cannot be "scientifically justified", it simply reflects a normative decision!!! This point is particularly important because the identity of different components of the society is not given from the outside once and for all (as done with cyborgs). The identity of elements of social systems (individuals, households, communities, countries to arrive at the meaning given to the concept of humankind) is the result of a continuous struggling, which is essential to maintain diversity and therefore the ability to learn and adapt.

4.3 Quality criteria of the semiotic process in human societies

4.3.1 The need of avoiding hegemonization ("cyborgization") in human societies

We saw that an instance of cockroach can validate (not for itself but for the species to which it belongs) the beliefs associated with its anticipatory models (Fig. 1) because: (i) both the identity and the purpose of the instance of cockroach are given – they are associated with the typology (species) to which the instance (specific organism) belongs; (ii) the space domain of the controls expressing the behavior of the instance is defined – the option space of agency of an instance of cockroach is defined by its genes; (iii) there is a correspondence between the descriptive domain used by its system of control and its space-time domain of agency. The situation is totally different when looking at the semiotic process taking place in a human society: (i) the identity of the system (the "whole" to which the various agents belong to) is systematically contested:

human agents are holons and therefore they can express simultaneously different "identities"; (ii) human societies are "holarchies" (Koestler, 1968) – autopoietic systems organized across different levels – so that there are various definitions of "identity and purposes" referring to different holons that co-exist across levels and express different patterns of behavior at different scales: individuals, households, local communities, national communities, macro-regions, the whole humankind and depending on the circumstances, these different identities may be used by the same instance in relation to different decisions to be made!; and (iii) inside a holarchy there is a natural tension between downward causation (top down definition of constraints on the lower level agents determined by the identity of the upper level holons) and upward causation (bottom up definition of purposes generated by the activity of lower level holons requiring changes in the behavior of the upper level holons).

In healthy holarchy the complexity of the holarchy is kept by establishing a "double asymmetry" across the holons – i.e. in democracies governments rule on citizens on the daily base, but citizens rule on governments at election time. Holons in a holarchy are the same time "rulers and ruled" (Grene, 1969). A similar concept has been introduced by Iberall et al. 1981 under the label of equipollence (a power balance across functional elements established across levels of organization). For this reason, it is essential to acknowledge the unavoidable existence of systemic contradictions in the different perceptions found in the holarchy (yin-yang relations): paying taxes is not good for households, but it is good for the community to which the household belongs. This implies that a healthy society has to find a way of handling this tension – i.e. both "types" and "instances" of institutions have to be continuously negotiated and re-discussed according to the evolution of power relations. In turn these institutions are essential to organize the expression of social practices, that have to be integrated across different space-time domains. *"A holarchy is no longer healthy when it loses its ability to share stress among different holons (balancing the focus between horizontal and vertical coupling, maintaining equipollence, being able to act under double asymmetric relations). This happens when policy indications developed according to one perspective (based on the description of what goes on at one level) become dominant over other legitimate and contrasting policy indications coming from descriptions referring to other holons . . . This is a sign that the continuous negotiation and interaction among holons within the holarchy (which is needed to avoid the process of decomplexification of the existing dynamics and controls) is no longer effective".* Giampietro, 2003 p.168-169.

An excessive hegemonization of story-telling in a society can generate a situation of "ancient régime" syndrome defined as 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" (after Funtowicz and Ravetz, 1994)

4.3.2 The semiotic process in human societies

An effective governance of the semiotic process – Fig. 9 - requires three types of input:
(i) an input coming from the top - selecting the relevant concerns and providing a prioritization over the story-tellings to be adopted – a step required in order to be able to deliberate over a limited option space in policy-making; (ii) an input coming from the right – providing a supply of knowledge-claims associated with anticipation in relation to explanations for identified problems; (iii) an input coming from the left - feeding-back the experience done by the complex of social practices needed to test, across scales and dimensions of analysis, the robustness of the endorsed knowledge claims.
The four different social roles in the semiotic process are: (i) observers – i.e. scientists, generating the representations; (ii) agents – i.e. social actors, expressing social practices (inside

and outside the market); (iii) decision makers, deciding how to use the controls (translating concerns and narratives into targets and policies); and (iv) story-tellers – i.e. the political process, defining the identity of the system, that is required for determining the priorities of action.
However, the proper operation of the semiotic process depends on a series of factors: (i) Do the agenda and the decision making of the incumbents match the stated agenda and the stated decision-making procedures of their institutional roles? (ii) Are the incumbents in the four social roles - observers, agents, decision makers and story-tellers - operating at the same scale (space-time domain), the same turn-over frequency and do they share the same selection of epistemic boxes? (iii) what are the implications of the relations of power over these four groups and how can power asymmetries affect the quality of the process? In conclusion, are these four social roles operating as a functional whole?

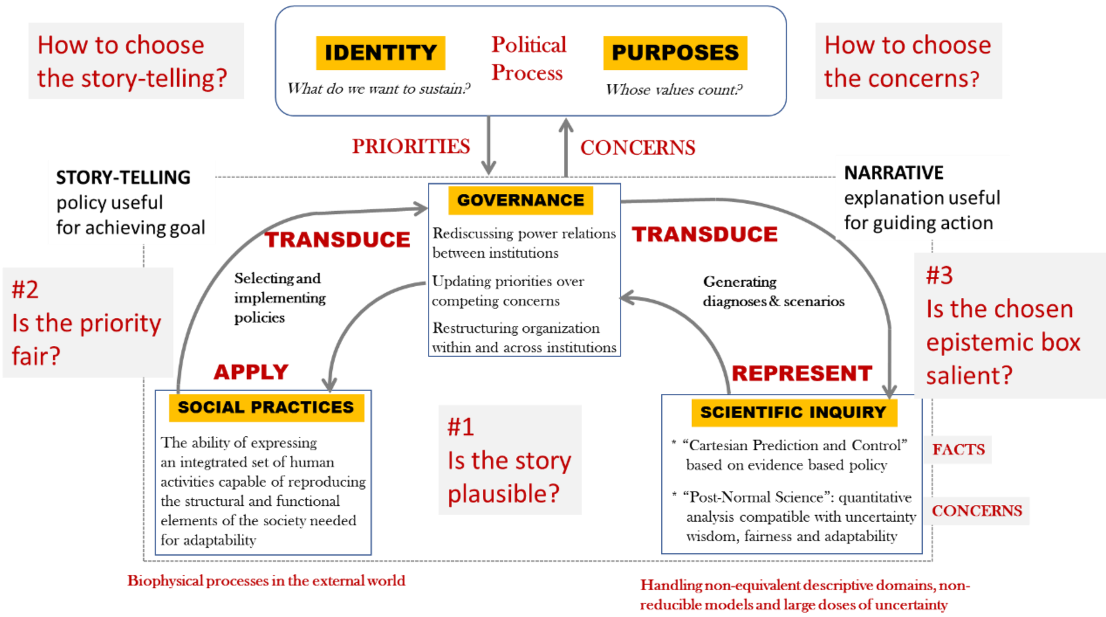

Fig. 9 Quality checks on the semiotic process used to validate scientific advice

Negative factors that can jeopardize the quality of the semiotic process have been identified by various authors using different concepts:
(i) 'Hypocognition' (Lakoff, 2010) – suggested this term to flag that any selection of a given framing of an issue implies hypocognition in relation to the aspects neglected by the framing. Similar formulations of this concept, but with a more positive take are: "*all models are wrong, but some are useful*" Box (1978). "*Models are 'blinders' which 'leaving out certain things', [...]provide a frame through which we see the world'* Stiglitz (2011);
(ii) socially constructed ignorance (Ravetz,1986; Rayner, 2012) - as explained by Rayner (2012) socially constructed ignorance "*is not the result of a conspiracy but of the sense-making process of individuals and institutions, to produce self-consistent versions of that world by expunging that knowledge which is in tension or contradiction with those versions*";
(iii) hegemonization of story-telling reflected into an hegemonization of normative narratives (Funtowicz and Ravetz, 1993). This hegemonization in the semiotic process generates a break of equipollence in the holarchy and as a consequence, in the decision-making process, "facts"

decided by those in power within the institutions take over "concerns" of the less powerful in society.

4.3.3 From scientific evidence to quantitative story-telling

When considering the complexity of the semiotic process, it would be wise to base policy decision not only on the results of analysis - "scientific evidence" - coming out of a single epistemic box (Cost-Benefit Analysis) or an extremely reduced number of epistemic boxes (MCA framing). Rather "scientific advice" should acknowledge the co-existence of different identities, purposes and concerns in society (Saltelli and Giampietro, 2017) and avoid to put all its epistemological eggs in a single basket. A scientific knowledge claim must be described in such a way that it must be capable of being redefined and understood also outside of its original epistemic box. For example, the accumulation of GHG in the atmosphere is just one of the many effects of the excessive pressure that human activity is generating on the biosphere. The problem of sustainability of humankind is not just about keeping the level of CO_2 in the atmosphere to avoid an increase of more than 1.5 degrees! Rather the targets referring to GHG emission should be integrated with other targets referring to other concerns referring to many other "losers" in relation to sustainability – e.g. the insects, the rural farmers in developing and developed countries, the soil, the cultural diversity of the planet. Concerns related to sustainability should include the health of ecosystems, the integrity of the natural processes going on in the biosphere, the health of social community and integrity of social practices established in the last millennia in the anthroposphere. These concerns cannot be addressed using a single number.

In relation to this point an EU project MAGIC (Moving to Adaptive Governance in Complexity - https://magic-nexus.eu/) has introduced an innovative approach, called Quantitative Story-Telling, to check the quality of narratives. Quantitative story-telling expands the quantitative analysis outside the narratives of economics by integrating biophysical narratives based on complex system theory and applies a procedure for checking the quality of scientific evidence used for governance. When dealing with a quality check of EU directives in 5 policy domains (water, energy, CAP, environment, Circular Economy) the narratives endorsed as story-telling in the process of decision making are first identified through a desk analysis of EU documents. Then the relevance of the selected narratives is validated through participatory processes with EU staff. Finally, the narratives that have been confirmed to be relevant for the choice of policies are tested in relation to three quality criteria:

PLAUSIBILITY – the story-telling must be plausible when considering the whole complex of social practices and not only the tiny perspective given by the adoption of an epistemic box - i.e. how credible that in less than 20 years the EU will be fully decarbonized, when considering that: (i) 80% of the energy consumed at the moment is fossil energy; (ii) we do not have at the moment any alternative source of liquid fuels; (iii) intermittent sources of electricity (when taking out hydroelectric power) cannot even cover 15% of electricity; and (iv) we do not have an integrated set of social practices capable of operating the existing metabolic pattern in a different way;

NORMATIVE FAIRNESS – the story-telling must be able to address the "tragedy of change" (Funtowicz and Ravetz, 1994). "*In order to be able to engage in new styles or ways of living (the proposed change) we must be able to sacrifice old styles and giving up an important fraction of the accustomed standards we are used to*" (Sorman and Giampietro, 2013). That is, the chosen epistemic boxes used to look at future achievements cannot miss concerns considered as relevant by a large number of people. More specifically, the narratives used in decision making must consider the two sets of concerns of the winners and losers associated with the implementation of a given policy (how much the winners win and how much the losers loose).

This information allows a "better informed" discussion of the policy and a better detection of potential biases introduced by lobbies. For example, if the switch to electric cars will imply threatening the German automotive industry with the loss of hundreds of thousands of jobs, should we include this side effect in the scientific analysis of the policy? Or should this consideration be added ex-post, as a political patch, after the policy decision has been made and the problem finally emerges? In general terms, should side effects be included in the anticipation? It is important to observe that this quality check on the side effects of policies translates into a quality check on the fairness of the process of policy making! Have the neglected side effects missed by chance or have they been occulted?

ANALYTICAL COHERENCE – the quantitative analysis of events has to be based on a robust theoretical basis and it must be coherent across scales and dimensions. This check requires looking at: (i) feasibility (compatibility with external constraints determined by processes outside human control); (ii) viability (compatibility with internal constraints determined by processes under human control) this check refers to both economic dimension and technical dimension of analysis; and (iii) desirability (compatibility with normative values and the stability of the social fabric). Unfortunately, at the moment the hegemonization of the use of economic narratives in the analysis of sustainability issues entails a systemic lack of coherence in the quantitative analysis that would be required to carry out these three quality checks across representations referring to different dimensions and scales.

5. Reflections on the evolution of the use of scientific evidence in the semiotic process within the society

5.1 From divination to enlightenment to disenchantment to democratization?

In the past, anticipation was carried out by oracles and seers. Modern experts would call these methods as "unscientific". Yet this "unscientific" science of anticipation was playing an important symbolic role in the semiotic process of ancient societies. The establishment was claiming to use trustworthy "knowledge claims" about anticipation at the moment of taking important decisions and this fact was reducing the social stress associated with the uncertainty about the future. It should be noted that this need of "unscientific" anticipation is still felt today as it can be easily checked by looking at the sections of astrology present in almost all the newspapers printed today.

After the enlightenment science played two key roles: (i) again a symbolic role - making it possible to replace the legitimization of the institutions of power given by God (religion) with the legitimization given by the "scientific process"; and (ii) a practical role solving the problems identified by the establishment and providing an "edge" on competing societies. After the enlightenment, more science and technology became equal to more power, both on the exterior and in the interior of the society. However, this excessive homologation of science with the power entailed a dangerous confusion. "*Early-modern practices introduced the notion that any rational person would reach the same conclusion about a given state of affairs only by following a pre-established rational procedure*" (Making sense of Science, 2019).

The concept of rationality defining the expected behavior of an economic agent is totally outside the mechanism of the creation of meaning in life. Meaning is created, in life, by combining different mixes of purposes, beliefs and interactions over agents across scales that are expressing a semiotic process. In the "rational behavior" the meaning of a rational person is given from the outside in the form of a cybernetic control. The rational agent is supposed to be without a special history, without any affect and expected to behave in the same way independently of age, gender and the specific socio-economic context. A rational person, therefore, can be considered as a cyborg (like the instance of cockroach described in Fig. 1) that is using a set of knowledge-claims (the "rational behavior") generated elsewhere and given to her/him just to test their validity by expressing an expected function. This type of cybernetic knowledge has been called *"replicant knowledge"* (Giampietro et al. 2007) to make reference to the characters of a science fiction movie ("blade runner") in which memories and wants were implanted in the brain of history-less and identity-less cyborgs – i.e. the replicants. Replicants were an equivalence class of story-tellers established and remaining forever "out of context" (even if materialized they remained still types and not instances). Replicant knowledge assumes that the given epistemic boxes are valid by default.

The hegemonization of the use of science to solve the problem identified by the establishment using economic narratives has generated, in the last decades, a certain feeling of disenchantment with scientific inquiry. In fact, the consistent utilization of a story-telling and epistemic boxes ignoring the concerns of the less powerful in the society and totally neglecting non-economic aspects of social practices has alienated a growing fraction of the society from the unconditional endorsement of the belief that science is capable of providing the solutions to all the problems faced by society. This disenchantment is growing not only because it is becoming clearer and clearer that the more we enlarge the domain of practical applications of scientific inquiry the more it becomes difficult to find solutions, but also because it is becoming clearer and clearer that when dealing with complex problems the key issue is not with *the identification of the solution* (after having identified a problem), but rather is with *the identification of the problem to be solved first* (taking action for whom?). Without a proper identification (agreement among different story-tellers!) of the nature of the problem it is impossible to gain a full understanding of the possible side effects of the chosen solution – i.e. *a war against poverty ends up by eliminating the poor!*

Looking at the current use of science and technology in the discussion over sustainability (e.g. the economics of technological promises – "yes we can fix the external world according to our wants") one has the impression that the main goal of science is still that of solving the problems of those that are in power – i.e. science is needed to stabilize the establishment. More innovations and more technology are needed to get better predictions and more control over "our future" (whose future?). An alternative strategy could be that of expanding and exploring the option space of feasible, viable and desirable metabolic states – anticipating troubles and exploring alternative combinations of social practices – reflecting the existence of a variety of concerns existing in society. In this different paradigm science should be use help a deliberation over priorities to be given to different concerns.

There are two other possible changes in the definition of the role of science that can be associated with a progressive process of democratization:
1. science should help to handle conflicts peacefully, reducing rather than increasing power asymmetries over winners and losers (e.g. the arm race in the past). When coming to "economic wars" the economics of technological promises expected to make EU winner in the in a globalized market probably will end-up by increasing sustainability problems by increasing the externalization of environmental impact elsewhere and by generating more economic immigrants;

2. science should look for adaptive, *temporary* and satisficing compromise solutions. Let's forget about "optimal" (for whom?) silver bullets fixing the given problem forever and be happy with clumsy solutions (Verweij and Thompson, 2008).

It is time that a more democratic science becomes also a more reflexive science.

Acknowledgement

This research was supported by the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 689669 (MAGIC). This work reflects the author's view only; the funding agency is not responsible for any use that may be made of the information it contains.

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