Position Paper

Implications of Complexity Theory

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1. Introduction

During the last decade, it has become increasingly clear—at least to those who want to see it—that our model of economic development is incompatible with the limits imposed on us by nature. Note that I am not only referring to climate change. Our current path of development is systematically de-stabilizing all ecological systems that collectively provide our life support system. For example, the 2019 IPBES report simply reveals a biodiversity horror story (IPBES, 2019). The continuous increase in population size and the growing expectations for a higher standard of living worldwide have caused us to move from an 'empty world' to a 'full world' (Daly, 1990; Goodland & Daly, 1990). While in the former resource availability per capita was sufficient to prevent us from perceiving the existence of limits to growth, in the latter these limits have become painfully evident. Nonetheless, policymakers pretend these limits can be overcome by business models and technical innovations, thereby resorting to policy legends and socio-technical imaginaries to retain legitimacy (Giampietro & Funtowicz, 2020; Jasanoff & Kim, 2015). Indeed, humans are ever more alienated from nature. The

Oxford Dictionary definition of nature, endorsed by organizations such as the OECD, speaks for itself: "Nature is the phenomena of the physical world collectively, including plants, animals, the landscape, and other features and products of the earth, *as opposed to humans or human creations*". This definition suggests that "*homo economicus"* is not part of nature nor evolved on this planet, as if we were instead rational cyborgs, with the sole goal of creating a growing economy independent of nature. (This may well explain the success of the EU circular economy action plan in which human society supposedly will no longer rely on the exchange of inputs and outputs with the biosphere).

Concurrent to and interrelated with the environmental collapse, we are experiencing a no less important cultural crisis. We are in an ideological cul-de-sac. It has become increasingly intolerable to live in a society in which the economy grows by destroying the environment, the rich become richer and the poor poorer, farmers disappear faster than other endangered species, and the only solution to maintaining a high standard of living is a legalized global "Ponzi scheme" (also known as "quantitative easing" or free printing of money for the rich). The profoundness of the crisis is evident from the fact that, in spite of paying lip service and showing indignation, we are accepting this situation that translates into losing social bonding, within and across societies. If people no longer believe in their ability to change things together, there is little policymakers can do. This loss of social bonding results from the progressive crumbling of our identity as individuals and as society. "The function of this new economy, legal and illegal, is to entertain and distract a population which - though it is busier than ever before - secretly suspects that it is useless" (Gray, 2002, p. 160).

Given these two challenges, the following questions arise. Can we change the current path of development toward a society that strives for caring for each other and the environment, rather than accumulating capital? Is such a transformation possible by relying on the neoliberal recipe of new business models (invisible hand of the market) and technical innovations (human ingenuity)? Can the sustainability and related political crisis be solved solely through the implementation of a series of technological fixes? These questions point to the key role that science should play in solving the sustainability crisis and the profound intoxication of the current debate by the Cartesian dream of prediction and control (Guimarães Pereira & Funtowicz, 2015). The persistent idea that we can solve any complex problem with "optimal solutions" delivered by carefully planned business models and advanced technologies prevents developed societies from considering "something completely different", like a caring economy. At present, it is unthinkable to explore alternative social practices unless the plan of action is “scientifically proven” and fully “under control” by the current establishment. The system of governance of contemporary society is no longer capable of handling uncertainty. This has led to a logical impasse. On the one hand, we are aware that ruling institutions (national governments and international bodies) have lost control and that our society has become fragile and susceptible to perturbations. On the other hand, we are reluctant to explore alternatives because we fear risking to lose even more control (as well as privileges). We, in the sense of both individuals and society as a whole, are scared of making changes. Given this situation, are scientists helping or making things worse? Can science handle complexity and uncertainty?

2. Narratives in sustainability science

A complex phenomenon is a phenomenon that requires a simultaneous perception and representation of its various relevant aspects using several non-equivalent narratives and dimensions and scales of analysis (Allen & Starr, 1982; Funtowicz & Ravetz, 1997; Giampietro, 2003; Giampietro et al., 2006; Rosen, 1977; Salthe, 1985; Simon, 1962). I define here a narrative as an epistemic device used by human beings to identify and describe relevant causal relations over events. A narrative is necessarily based on a given (particular) point of view of the external world. It provides explanations that are potentially useful for informing action; the extent of usefulness being dependent on the purpose of the chosen narrative. That is, the choice of a narrative is made in a pre-analytical phase, before the modeling and quantification associated with scientific work takes place. A narrative entails the choice of a descriptive domain (the space-time scale and dimension of analysis), but in order to be relevant it has to be useful for an agent having a specific purpose. A narrative permits identifying the set of attributes (what has to be observed) relevant for the representation (the models).

The epistemological predicament of complexity for science entails that any model that generates an exact description of the observed system and provides crisp numbers can only do so because it only describes a finite set of attributes, which the scientist decided to use in the description of the system based on her/his narrative. As eloquently stated by Box (1979), “*All models are wrong. Some are useful*”. The usefulness referred to will depend on the quality and the coherence of the choices made in both the pre-analytical and analytical steps of the investigation (Giampietro et al., 2006). In the same spirit, Lakoff (2010) suggests that any framing of a problem entails “hypocognition”, especially when the framing is associated with the choice of quantitative variables. In other words, the chosen framing ignores a large set of relevant aspects of the problem at hand.

In **Figure 1**, I illustrate my point with a simple example using different combinations of narrative, storyteller and contextualization. In the first column (on the left), we have a list of four narratives along with the context in which they are proposed. In the second and third columns, we have different story-tellers/users who are expected to endorse and use (one of) the explanations for guiding their action.

NARRATIVE	Story-Teller/User	Story-Teller/User
EXPLANATION 1 → "no oxygen supply in the brain" *Space-time scale*: VERY SMALL *Example*: EMERGENCY ROOM	Virologist	Doctor in the emergency room
EXPLANATION 2 → "affected by COVID 19" *Space-time scale*: SMALL *Example*: MEDICAL TREATMENT	Philosopher	Pharmaceutical Researcher
EXPLANATION 3 → "lack of an adequate vaccination in the population" *Space-time scale*: MEDIUM *Example*: MEETING AT HEALTH MINISTRY	Doctor in the emergency room	Virologist
EXPLANATION 4 → "human must die" *Space-time scale*: VERY LARGE *Example*: SUSTAINABILITY ISSUES	Pharmaceutical Researcher	Philosopher

Figure 1. Non-equivalent narratives about the death of a person showing that narratives are neither true nor false, but useful or useless

If we look at the list of story-tellers/users in the second column, it is evident that none of the corresponding explanations provides any useful insight for guiding their action. On the contrary, if we consider the last column of story-tellers/users, all the chosen narratives provide useful information for their purposes. This shows that scientific explanations based on a pre-analytical choice of a narrative of a phenomenon are neither true nor false, but they may be useful or useless.

The point that the usefulness of a narrative depends on the nature of the concern of the story-teller is further elaborated in **Figure 2**. In this example, rather than providing a list of explanations, I show a list of story-tellers/users of a chosen narrative (in this case, different scientific experts participating in a single conference) and their advice on how to achieve a desirable and fair food policy. Note that, in contrast to the previous one, this example has not been made up, but rather reflects presentations and discussions in a scientific conference in which I participated.

Different Story-tellers!	Story-telling about National Policy	
I.F.P.R.I. - U.S. scientist	Keep prices of food commodities LOW	Protecting the urban poor
Ag. Econ. - Prof. from Pakistan	Keep prices of food commodities HIGH	Protecting the poor farmers
	Story-telling about International Policy	
Wuppertal Inst. – from Germany	REDUCING imports from the South	Avoiding externalization
Ag. Dev. - Prof. from Ghana	INCREASING imports from the South	Developing the agricultural sector
	Story-telling about Social Policy	
NGO - Swiss Feminist	PRESERVING local cultural heritage	Protecting cultural diversity
Sociologist - Prof. from India	FIGHTING local cultural heritage	Protecting wives burned alive together with dead husbands

Figure 2. Contrasting scientific advice of different experts/story-tellers at the SAGUF World Food Conference, Zürich, 9-10 October 1996

The contrasting advice provided by the invited experts refers to three different aspects of food security (national policy, international policy, gender issue). All the advice was given by reputable scientists and supported by convincing evidence. However, if we look at Figure 2, we see that, depending on the problem the expert wants to solve (i.e., the purpose/prioritized concern of the agent), a pertinent advice can be legitimately in contrast with another pertinent advice (e.g., protecting the nutrition of the urban poor versus protecting the income of poor farmers). Hence, the purpose of the food policy (the choice of the problem to be solved) can be associated with the "identity" or cultural context of the story-teller, which determines the priority of the concern to be addressed. In this particular example, all the story-tellers from developed countries suggested policies that stabilize the status-quo (considered desirable), whereas those from developing countries suggested policies that aimed at changing the status-quo (considered undesirable). This example demonstrates that the quality of the process of policymaking cannot be analyzed in scientific terms only.

The contrasting advice reflects the existence of trade-offs over different points of view of sustainability. But how to establish priorities over the concerns of the various social actors? In the first case, the concerns of the urban poor are weighted against the concerns of the rural poor. Protecting the urban poor by keeping food prices low translates into low revenues for farmers, who consequently will not be able to invest in producing more food. Nonetheless, a larger supply of food, if more expensive, will not necessarily help the urban poor.

In the second case, developed societies, by importing food commodities from developing countries, are externalizing environmental stress to ecosystems located in the exporting countries. However, if the rich countries stop importing food commodities they hamper the economic development of the agricultural sector of developing countries that enjoys comparative advantages (lower cost of production). In this case, the concern for the environment (in developed countries) contrasts with the concern for a low level of economic development (in developing countries).

The last example in Figure 2 about social policy is even more striking. While nobody would object to the need to preserve cultural traditions and identity across the globe – given the key role played by women in guaranteeing food security, it is also true that there are specific situations (like the one shown in Figure 2) in which it may be opportune to change the local cultural heritage. Again, in this example it is evident that generalizations and written rules cannot be applied without considering the specific context and the point of view and the emotions of people experiencing the event represented in the scientific analysis. Scientists alone, without interacting with the society within which they are operating, cannot deal with the prioritization of concerns. For this reason, it is essential for scientists to carry out a continuous revision of the "meaning" and "usefulness" of the narratives used to generate their representation in relation to the evolving context. This entails that we have to continuously revise, in an iterative process, what are the concerns to be addressed by society, how to define our affective interactions, and how to identify the social practices that reinforce a caring society. In this process of evolution, we have to be open and flexible when scientific narratives and models are in need of updating.

3. What role for sustainability scientists?

The terms "sustainability science" and "the science of sustainable development" were 'officially' coined in 1999 by the National Research Council (National Research Council, 1999). Many different definitions and views of sustainability science soon followed (see, for example, Fang et al., 2018; Kajikawa, 2008; Miller, 2013; Spangenberg, 2011; Ziegler & Ott, 2011). Perhaps the most ambitious is the following definition of Kates et al. (2001), in an influential paper in *Science* (emphasis in italics is mine):

> "A new field of sustainability science is emerging that seeks to understand the fundamental character of interactions between nature and society. Such an understanding must encompass the interaction of global processes with the ecological and social characteristics of particular places and sectors (..). The regional character of much of what sustainability science is trying to explain means that relevant research will have to integrate the effects of key processes across the full range of scales from local to global (..). It will also require fundamental advances in our ability to address such issues as the behavior of complex self-organizing systems as well as the responses, some irreversible, of the nature-society system to multiple and interacting stresses. *Combining different ways of knowing and learning will permit different social actors to work in concert, even with much uncertainty and limited information.*"

Martens (2006) and Spangenberg (2011) point out that science of sustainability concerns a new research paradigm that recognizes uncertainty and exploration (as opposed to prediction) and emphasizes the importance of co-production and co-learning through an extended peer community and stakeholder engagement.

Indeed, as noted, it is particularly important to define not only "what sustainability science is about", but also "who are the social actors in charge to generate this new type of science". A passionate call in the direction of radical change in the conception and definition of sustainability science has been made by the community of Post-Normal Science (PNS) (Funtowicz & Ravetz, 1993; Funtowicz & Ravetz, 1990, 1994). PNS is an alternative approach for the use of science for issues where "facts [are] uncertain, values in dispute, stakes high and decisions urgent". The rationale of PNS is summarized by the iconic graph shown in **Figure 3**, which illustrates that the credibility of the "normal" scientific approach (in the interpretation of Kuhn) becomes increasingly controversial as the level of decision stakes and system uncertainty grows. This graph neatly shows the different roles that scientists should play in different situations.

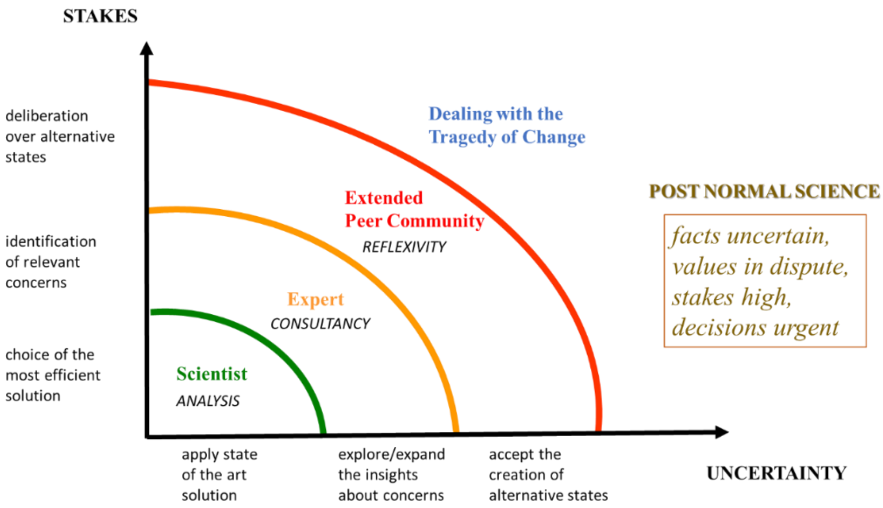

Figure 3. The iconic diagram of Post-Normal Science proposed by Funtowicz and Ravetz in relation to the different uses of science and roles of scientists in different situations.

Understanding the differences between these roles is essential to perceive the special role that scientists should play when asked to provide input about sustainability. The three roles indicated in the diagram are:

1. “Normal” scientist - when scientific input refers to an issue in which we can assume a low level of uncertainty and a clear definition of stakes (e.g., building a bridge). In this role, scientists are expected to apply known procedures. This case refers to a situation in which the available knowledge claims about how to build bridges are robust and uncontested. In this case, the pertinence and the rigor of the analysis are sufficient to guarantee the quality of the scientific work.

2. Expert - When the issue is more complex and it is essential to also consider the points of view of those that will use the scientific input, scientists have to play the role of the expert. They have to:

i. identify the possible concerns that can be associated with the given action (e.g., a delicate surgery), i.e., the pros and cons of possible consequences,

ii. explicitly address the level of uncertainty of the expected results – e.g., the possibility and consequences of failure; and

iii. openly discuss with the user the prioritization over contrasting concerns in relation to the acknowledged existence of uncertainty.

In this role, scientists cannot decide on their own, they have to co-produce their decisions with those who will be affected by the choice(s) made.

3. Post-normal scientist - When facing a situation in which radical changes are needed that imply an adjustment of the identity of both the society (the cultural context) and the different agents involved in the decision process, things become different. In this situation "facts are uncertain, values in dispute, stakes high and decisions urgent" (Funtowicz & Ravetz, 1993, p. 744) and nobody, neither the social actors nor the scientists, can claim knowing what is the best thing to do, let alone having an effective method to prioritize contrasting concerns. In this case, the decisions have to be based on an informed deliberation of an extended peer community. However, this type of decision is no longer based on available knowledge claims (referring to something that does exist and has been experienced), but on something that does not exist and has to be created together by the coordinated action of society. In relation to this creation, particularly important are the emotions, feelings, hopes, and fears in determining the ability to maintain the current set of affective interactions. The society has to prioritize the protection of the social bonding. In this situation, the option of "fixing the external world according to our will" no longer exists because we simply do not have a robust, reliable and uncontested plan based on an uncontested agreement of "who we are" and "what we want to be". Rather we have to learn how to explore the option of "changing our identity and social practices in order to become more respectful of nature and more caring for each other".

Certainly, scientists can play a key role in this learning. However, they have to forget about the Cartesian dream and abandon the hegemonic use of orthodox neo-liberal narratives that see human society as distinct from nature. Scientists should help society to recognize that human beings must learn how to care for each other while living within the limits imposed by nature because to nature they belong.

4. Conclusions

It is time that developed societies accepted that we must learn how to go through the tragedy of change. We are part of nature and we have to co-evolve with nature. We simply cannot impose our will on nature, nor control her. In this dire environmental and social crisis, it is important that scientists properly play their role. Rather than endorsing the hubris associated with the Cartesian dream of prediction and control, scientists should acknowledge the complexity of the sustainability predicament and flag the need for considering various different narratives and strategies, including relying more on our common sense and feelings. There is no shame in starting a discussion over the sustainability predicament with a sobering acknowledgment that we have a problem and that we do not know how to solve it. More silver bullets or the invisible hand of the market simply cannot solve our sustainability problems. Only a radical change in social practices based on a shared understanding that what society needs is less capital and more caring can put us on the path toward a more sustainable and equitable development.

Socrates warned scientists to be wary of their own ignorance. In sustainability science, this advice is particularly pertinent. It is not the task of the scientist to control nature but to help society understand that we are part of it. Scientists should interact with the rest of society to co-generate a collective reflection on the existence of natural limits and discuss with all societal actors 'desirable' future pathways. This special issue shows creative ways of how this can be pursued in practice.

References

Allen, T. F. H., & Starr, T. B. (1982). *Hierarchy: Perspectives for Ecological Complexity*. University of Chicago Press.

Box, G. E. P. (1979). Robustness is the strategy of scientific model building. In R. L. Launer & G. N. Wilkinson (Eds.), *Robustness in Statistics*, Academic Press, pp. 201–236.

Daly, H. E. (1990). Toward some operational principles of sustainable development. *Ecological Economics*, *2*(1), 1–6. https://doi.org/10.1016/0921-8009(90)90010-R

Fang, X., Zhou, B., Tu, X., Ma, Q., & Wu, J. (2018). "What Kind of a Science is Sustainability Science?" An Evidence-Based Reexamination. *Sustainability*, *10*(5), 1478. https://doi.org/10.3390/su10051478

Funtowicz, S. O., & Ravetz, J. R. (1993). Science for the post-normal age. *Futures*, *25*(7), 739–755. https://doi.org/10.1016/0016-3287(93)90022-L

Funtowicz, S. O., & Ravetz, J. R. (1997). The poetry of thermodynamics. *Futures*, *29*(9), 791–810. https://doi.org/10.1016/S0016-3287(97)00059-1

Funtowicz, S., & Ravetz, J. (1990). *Uncertainty and Quality in Science for Policy*. Kluwer Academic Publishers.

Funtowicz, S., & Ravetz, J. R. (1994). Emergent complex systems. *Futures*, *26*(6), 568–582. https://doi.org/10.1016/0016-3287(94)90029-9

Giampietro, M. (2003). *Multi-Scale Integrated Analysis of Agroecosystems*. CRC Press.

Giampietro, M., Allen, T. F. H., & Mayumi, K. (2006). The epistemological predicament associated with purposive quantitative analysis. *Ecological Complexity*, *3*(4), 307–327. https://doi.org/10.1016/j.ecocom.2007.02.005

Giampietro, M., & Funtowicz, S. O. (2020). From elite folk science to the policy legend of the circular economy. *Environmental Science and Policy*, *109*, 64–72. https://doi.org/10.1016/j.envsci.2020.04.012

Goodland, R., & Daly, H. E. (1990). The missing Tools (for sustainability). In C. Mungall & D. J. McLaren (Eds.), *Planet Under Stress. The Challenge of Global Change*. Oxford University Press.

Gray, J. (2002). *Straw Dogs: Thoughts on Humans and Other Animals*. Granta.

Guimarães Pereira, A., & Funtowicz, S. (2015). *Science, Philosophy and Sustainability : the End of the Cartesian dream*. Routledge. https://doi.org/10.4324/9781315757902

IPBES. (2019). *Global Assessment Report on Biodiversity and Ecosystem Services | IPBES*. https://ipbes.net/global-assessment-report-biodiversity-ecosystem-services

Jasanoff, S., & Kim, S.-H. (2015). *Dreamscapes of Modernity - Sociotechnical Imaginaries and the Fabrication of Power*. University of Chicago Press. https://doi.org/10.7208/chicago/9780226276663.001.0001

Kajikawa, Y. (2008). Research core and framework of sustainability science. In *Sustainability Science* (Vol. 3, Issue 2, pp. 215–239). Springer. https://doi.org/10.1007/s11625-008-0053-1

Kates, R. W., Clark, W. C., Corell, R., Hall, J. M., Jaeger, C. C., Lowe, I., McCarthy, J. J., Schellnhuber, H. J., Bolin, B., Dickson, N. M., Faucheux, S., Gallopin, G. C., Grübler, A., Huntley, B., Jäger, J., Jodha, N. S., Kasperson, R. E., Mabogunje, A., Matson, P., … Svedin, U. (2001). Sustainability Science. *Science*, *292*(5517), 641–642. https://doi.org/10.1126/science.1059386

Lakoff, G. (2010). Why it Matters How We Frame the Environment. *Environmental Communication*, *4*(1), 70–81. https://doi.org/10.1080/17524030903529749

Martens, P. (2006). Sustainability: science or fiction? *Sustainability: Science, Practice and Policy*, *2*(1), 36–41. https://doi.org/10.1080/15487733.2006.11907976

Miller, T. R. (2013). Constructing sustainability science: Emerging perspectives and research trajectories. *Sustainability Science*, *8*(2), 279–293. https://doi.org/10.1007/s11625-012-0180-6

National Research Council. (1999). Our Common Journey. In *Our Common Journey: A Transition Toward Sustainability*. National Academies Press. https://doi.org/10.17226/9690

Rosen, R. (1977). Complexity as a System. *International Journal of General Systems*, *3*(4), 227–232. https://doi.org/10.1080/03081077708934768

Salthe, S. N. (1985). *Evolving Hierarchical Systems*. Columbia University.

Simon, H. A. (1962). The architecture of complexity. *Proceedings of the American Philosophical Society*, *106*(6), 467–482. https://www.jstor.org/stable/985254?seq=1#page_scan_tab_contents

Spangenberg, J. H. (2011). Sustainability science: A review, an analysis and some empirical lessons. *Environmental Conservation*, *38*(3), 275–287. https://doi.org/10.1017/S0376892911000270

Ziegler, R., & Ott, K. (2011). The quality of sustainability science: A philosophical perspective. *Sustainability: Science, Practice, and Policy*, *7*(1), 31–44. https://doi.org/10.1080/15487733.2011.11908063

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The author has declared that no competing interests exist.