4 The entropic nature of the economic process

A scientific explanation of the blunder of circular economy

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Introduction

In the sixth century, the book *Christian Topography* described the Earth as a flat structural element on which very high walls were supporting heaven. This belief was held at the time by essentially all of European society in spite of the fact that a full millennium earlier Greek scientists had showed convincingly that the Earth was spherical (APS, 2006). In this chapter, I claim that the current social endorsement of the plausibility of a circular economy presents a sort of a *déjà vu* situation. In both cases, flat Earth and circular economy, we are dealing with a phenomenon referable to as: "[s]ocially constructed ignorance in science and environmental policy discourse" (Rayner, 2012). As explained in his paper, Rayner (ibid, emphasis added) writes:

> *To make sense of the complexity of the world so that they can act, individuals and institutions need to develop simplified, self-consistent versions of that world. The process of doing so means that much of what is known about the world needs to be excluded from those versions, and in particular that knowledge which is in tension or outright contradiction with those versions must be expunged.* ***This is uncomfortable knowledge****.*

This mechanism explains why the availability of robust information about the implausibility of a narrative used to justify a knowledge claim or a given policy, if sufficiently uncomfortable, may rather become an "unknown known" in the policy arena than be given due consideration. Such uncomfortable knowledge, even if easily available to those willing to find it, is simply expelled from the discourse.

In relation to this mechanism, a European project, Moving Towards Adaptive Governance in Complexity (MAGIC, https://magic-nexus.eu/), has been tracking the systemic exclusion of uncomfortable knowledge in the different processes used to select European Union (EU) policies across several policy domains relevant to sustainability. The policy domain of "circular economy" was one of the case studies of MAGIC. Findings from that case study are used to inform the text of this chapter. Those interested in the presentation of the results

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of MAGIC in video format (as well as in scientific paper format) are invited to check the Uncomfortable Knowledge Hub (https://uncomfortableknowledge.com/) website.

The text of this chapter is structured as follows. Section "Essential knowledge from the field of non-equilibrium thermodynamics" presents what is scientifically known about the process of self-organization of complex adaptive systems, a class of open systems to which social-ecological systems belong. Section "What happens if we use this knowledge to study the circularity of the economy?" illustrates a proper characterization scheme, which should at a minimum be followed when accounting for the metabolic pattern associated with the economic process. This characterization scheme is required to check the level of circularity of the economic flows in a social-economic system. When properly assessed, we can see that there is indeed no significant circularity in the metabolic process associated with the economic process. Section "The prophecy of Habermas" addresses the ideological reasons pushing our modern welfare democracies to deem the findings of non-equilibrium thermodynamics as "unknown knowns". This social construction of ignorance serves to steer the political discussion away from the implications of this uncomfortable knowledge. The final section concludes.

Essential knowledge from the field of non-equilibrium thermodynamics

We all know that complex adaptive systems (e.g., living systems and social systems) require a continuous process of energy and material conversions to preserve their identity and express their functions. However, the relation between identity preservation within this class of systems and the continuous process of dissipation has proven difficult to study within the field of classical physics (Giampietro et al., 2013). In fact, when considering the term "energy" in physics—standardly "the ability to do work"—we are faced with a tautological definition. That is, the apparent definition of energy requires a separate, pre-analytical definition of a special type of work. Work in physics is moreover about the effect of a "force", but its quantification does not make any reference to the time dimension. In relation to this impasse in the ability to deal with energetic transformations, the field of classical thermodynamics entered as a first attempt to generate a systemic classification of patterns of energy transformations, that is, thermodynamic cycles. However, the development of classical thermodynamics was based on the adoption of a series of "heroic assumptions" about the functioning of these cycles—no frictions, infinite time durations, and conditions of equilibrium to allow the measurement of the value of the relevant variables. Despite its heavy reliance on theoretical assumptions, equilibrium thermodynamics "represented a first departure from mechanistic epistemology by introducing new concepts such as irreversibility, symmetry breaking and indeterminacy: when describing real world processes nothing can be the same (e.g., the same state) when it happens for the second time" (Giampietro et al., 2013). The concept of entropy was key in this revolution. In classic thermodynamic analysis, the concept of entropy was associated with the idea of unavoidable decay of thermodynamic systems operating out of equilibrium. That is, sooner or later the gradients that allow the system to be perceived as an entity distinct from its environment are bound to disappear, meaning, according to equilibrium thermodynamics, complex patterns of energy and material transformations are transient patterns destined to disappear. A flame goes out when it runs out of fuel, a tornado dissolves when it loses the energy that formed it, living systems die without food, and so forth.

Unfortunately, the general conclusion that complex patterns dissipating energy are bound to disappear and the resulting prophet-of-doom association with the concept of entropy was inconsistent with experience. In our daily experience, we find that complex adaptive systems thrive all around us in the biosphere. Classical thermodynamics was providing an unsatisfactory analysis of the phenomenon of life and, more in general, of the existence of complex adaptive systems. Hence, not surprisingly, the field of thermodynamics experienced a second, more profound revolution in the scientific analysis of energy transformations, that of non-equilibrium thermodynamics. The curse of decay associated with entropic processes applies only to closed systems in which functional organization will be eliminated by a continuous and inexorable growth of entropy. For this reason, the focus of analysis in non-equilibrium thermodynamics moved to *open* dissipative systems in which a given dissipative structure can maintain its own identity due to the interaction with its context. Schrödinger (1967, in an added note to Chapter VI of *What is Life*, first published in 1945) provided the solution to the problem: open systems can compensate for the harmful pace of generation of positive entropy if they have available a negative flux of entropy coming from their environment. That is, open systems can export internally generated entropic surplus to the environment wherever and whenever their environment can absorb it. This idea was developed further by the work of the Prigogine school (Prigogine, 1961; Glansdorf & Prigogine, 1971; Nicolis & Prigogine, 1977; Prigogine & Stengers, 1984) with the introduction of a new class of physical systems—*dissipative systems*. Dissipative systems are *open systems* that can preserve a given identity expressed by specific dissipative structures—structures that can be observed as distinct from their environment and can be predicted in terms of expected attributes. This conceptual framing standardly indicates the relation between a dissipative structure and its environment using the following iconic equation, pointedly describing the condition of stability of the dissipative system:

$$+dSi - dSe \leq 0.$$

It should be noted that this discussion of positive internal entropy generation (+dSi) and external negative entropy fluxes (−dSe) is based on concepts in which the distinction between ontology and epistemology is blurred (Mayumi & Giampietro, 2004). Indeed, the term entropy has been an attractor of scientific discussions giving different meanings and different definitions to it, such as in classical thermodynamics, information theory, non-equilibrium thermodynamics, and so forth. Hence, we should not expect an uncontested agreement over how to define quantities of positive or negative entropy, but we must use these semantic relations to develop heuristic methods of analysis (more on this below). In any case, a given dissipative structure: (i) requires a continuous flow of energy and material (metabolic inputs) taken from its context, such as humid air for a tornado, food for an organism, a mix of commodities for a city; and (ii) generates a continuous flow of degraded energy and materials (metabolic outputs) dumped into its context. The establishment of this metabolic pattern—the stabilization of a metabolic flow—entails the ability to establish an expected set of relations over the set of transformations of different energy and material elements associated with the interactions the dissipative structure has with its admissible environment.

How does this discussion relate to the circular economy? When considering the factors determining the stability of a dissipative structure, we must first observe that the narrative of "circular economy" represents a major step forward compared with the old framing of neo-classical economics. This new economic narrative finally admits that the economic process requires a continuous flow of material and energy (those that must be recirculated). However, this narrative is unfortunately based on the exclusion of a very "well-known fact": dissipative systems *must be open*. That is, the concept of circularity is based on the erroneous assumption that it is possible to maintain the identity of a dissipative system by recirculating inside it the primary flows (those flows coming from and going to its environment) needed to preserve its identity. In fact, every time we add a new activity to an economic system (e.g., to increase the level of recycling of internal material and energy flows), we introduce a new source of +dSi. Obviously, the increase of +dSi caused by recycling activities can reduce the pace of generation of +dSi from other activities. Regardless, to explore the plausibility of the "circularity solution", it is important to properly frame the analysis over the factors determining the sustainability of a dissipative structure.

What happens if we use this knowledge to study the circularity of the economy?

Before getting into an illustration of the application of the rationale of non-equilibrium thermodynamics to the analysis of sustainability, it should be noted that, primed by the pioneering work of Kenneth Boulding (1966) and Georgescu-Roegen (1971), there is a line of research on the application of thermodynamic reasoning to the study the sustainability of the economy, among others Dyke (1988), Mayumi (2001), Giampietro et al. (2012), Friend (2012). For an overview of applications of the concept of entropy in the field of ecological economics, see Mayumi and Giampietro (2004).

To study the factors determining the sustainability of the economic process, we must start from the conceptual definition of a *dissipative structure*—the observable aspect of a dissipative system. A dissipative structure is generated by the establishment of a dynamical regime that can be considered as a reproducible steady state determined by the interaction with the context. Examples include a tornado, an organism, and a city. When dissipative structures are able to store information to guide their own reproduction (e.g., using genetic information or a language), they can learn how to adapt (expanding the set of meaningful behaviors they can express). In this case, we are dealing with complex adaptive dissipative systems (Giampietro, 2018). The possibility of storing information about how to preserve and adapt the identity of a dissipative structure is key as it allows the definition of the expected set of energy and material forms that are degraded inside the system. That is, the identity of a dissipative structure defines the mechanisms associated with the production of +dSi requiring a given mix of inputs. For example, inside terrestrial ecosystems: (i) plants need a mix of inputs including solar radiation, water, CO_2, and other nutrients; (ii) herbivores need a mix of water and plants; (iii) carnivores need a mix of water and herbivores; and (iv) detritus feeders have yet another definition of the mix of inputs they need internally to reproduce themselves and express their expected functions. In human societies, we can identify the required mix of inputs needed for sustaining both the physiological processes taking place inside the human body and the technological processes under human control. We cannot define in general terms a quantitative definition of +dSi and −dSe that is applicable to any dissipative systems. However, the conceptualization provided by non-equilibrium thermodynamics allows to "tailor" this quantification on any given type of dissipative structure. The identity of the dissipative structure, that is, a rural community or a post-industrial economy, can be associated with a given requirement and consumption of a mix of inputs needed for its positive entropy production (+dSi)—what is called in the jargon of energetics "exergy degradation". Then by tracking the primary flows needed to generate these inputs, we can identify the environment's capacity required to stabilize these primary flows both on the supply side (flows coming from the environment) and the sink side (flows going into the environment). In this way, we can generate a quantitative characterization of the flux of "negative entropy" (−dSi).

In conclusion, the expression of a dissipative structure entails establishing a relationship between two different categories of material and energy flows, which are observable either from inside or outside the given metabolic pattern, as illustrated in Figure 4.1:

1) Flows in the internal STATE. Inside the system, we can observe what is happening, that is, the pattern of dissipation of known exergy forms (+dSi). Here secondary and tertiary flows produced and used under human control are represented. These secondary and tertiary flows are needed for reproducing structural elements and expressing the set of required functions.
2) Flows determining an external PRESSURE. Outside the system we can observe the flows exchanged by the system with its context (−dSe). The interaction between the technosphere and the biosphere can be characterized by tracking primary flows. The stabilization of these flows requires a given quantity of supply and sink capacity (a flux of negative entropy coming from nature) capable of compensating for the production of positive entropy in the technosphere.

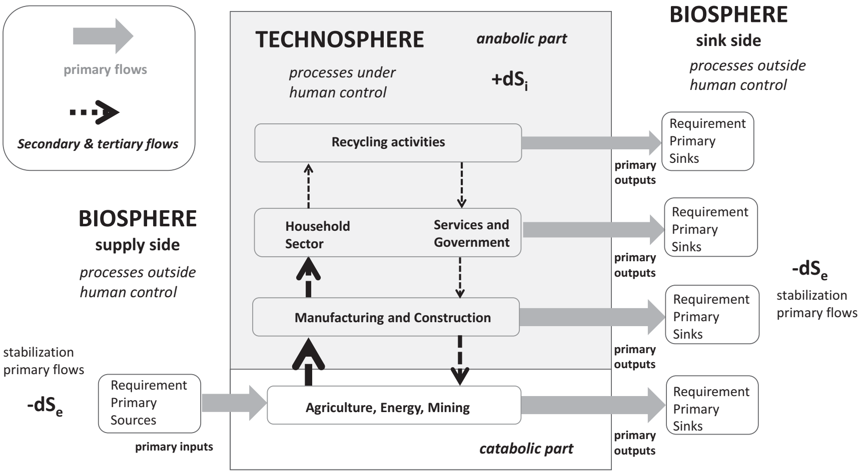

Figure 4.1 Different typologies of flows in the metabolic pattern of the economy: primary flows between the biosphere and the technosphere as well as secondary/tertiary flows between the economic sectors.

Source: own figure.

As illustrated in Figure 4.1, the sustainability of the economic process depends unavoidably on the existence of natural processes capable of maintaining stable boundary conditions. The pressure associated with a given metabolic state must remain admissible in relation to the integrity of environmental processes. Excessive pressure can damage the stability of favorable boundary conditions by damaging the life support system of the dissipative structure—generating an excessive impact on the environment, such as major soil erosion, depletion of a water table, accumulation of greenhouse gases in the atmosphere, or so forth. This distinction between the different categories of flows is essential to clear the confusion about the accounting of water, energy, mineral, and food flows in the "circular economy". Note that the terms "water", "energy", "mineral", and "food" are mere semantic labels in the narrative of metabolic flows and cannot be used as such to carry out a quantitative study on circularity (Giampietro, 2019).

In the analysis of the metabolism of social-ecological systems—a new class of systems proposed to help with the analysis of the interaction of the economic process with the biosphere (Berkes et al., 1998, 2003)—we must make a distinction between the activities of the catabolic part and the anabolic part in the metabolic process. Within the socio-economic process, these two parts handle different types of "water", "energy", and "food". The activities of the catabolic part take place in the primary production sectors of the economy (agriculture, energy, and mining). They destroy gradients freely provided by nature (primary resources and services) to make available secondary flows to the rest of society. The activities of the anabolic part take place in the remaining sectors of the economy (residential, manufacturing and construction, service and government, recycling). This part generates products and materials needed to build and maintain the structural elements of the society, guarantee the reproduction and the quality of life of humans, and produce adaptable institutions.

Note that the secondary and tertiary flows within the metabolic pattern are at the same time inputs and outputs: "In the anabolic compartment secondary inputs are both produced and consumed in the economic process". The secondary outputs of a given primary sector (e.g., the supply of electricity, food, materials, or products) become secondary inputs to other sectors in the catabolic part but also in the anabolic part itself (e.g., the consumption of electricity, food, mineral, or products in the economy). The production of secondary outputs is conditional on their being useful as input by some other metabolic elements; otherwise, they would not be produced in the first place (Giampietro, 2019). This fact may explain the idea of "circularity" in the economic process. Indeed, when adopting a conventional economic narrative of the economic process, we only allow ourselves to observe secondary and tertiary flows inside the technosphere (the ones regulated by market transactions). However, looking at Figure 4.1, it is obvious that there is no recycling of primary flows in the technosphere.

A last, important piece of information given by the relations shown in Figure 4.1 is that recycling is not a panacea. That is,

> According to the first principle of thermodynamics energy cannot be produced. We cannot increase the size of primary energy sources, but only learn how to use them better. According to the second principle of thermodynamics irreversible processes alter the qualitative characteristics of material flows. Recycling can be done, but only to a certain extent and at a certain cost, and only if the corresponding primary resources are available. Hence, the amount of primary waste outflows of an economy can be reduced by recycling (provided the inputs required by the recycling process itself do not exceed the waste outflow recycled), but a continuous production of wastes is unavoidable.
>
> (Giampietro, 2019)

The prophecy of Habermas

It is at last time to go back to the phenomenon of socially constructed ignorance discussed in the introduction, which works to explain the desperate need of the current establishment to expunge uncomfortable knowledge from policy discussions over sustainability. In relation to this point, it is relevant to recall the prophetic concern of Habermas (1979) about the existence of a systemic legitimation problem in social welfare state mass democracies. Habermas argued that, after abandoning the "dangerous" nationalistic mechanism of formation of a common identity adopted in the past, modern states base their legitimacy on the claim that they can solve all the sustainability challenges perceived by their constituent members, thereby keeping their stress low. This point is extremely clear when reading the justifications used by the EU to defend its policies. Looking at the ecological transition promised with the European Green Deal "the European Green Deal will transform the EU into a modern, resource-efficient and competitive economy, ensuring: no net emissions of greenhouse gases by 2050; economic growth decoupled from resource use; no person and no place left behind" (European Commission, 2021). The only possible solution when faced with this implausibly tall order is endorsement of and reliance on socio-technical imaginaries, which can be defined as "collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology" (Jasanoff and Kim, 2015). Socio-technical imaginaries are effective not only in reducing feelings of stress in society ("yes, we can") but also in allowing a transformation of extremely delicate political issues into mere technical ones (Strassheim & Kettunen, 2014; Funtowicz & Ravetz, 1990; Wynne, 1992; Schumaker, 1973; Winner, 1989) which can be solved without major confrontation. To paraphrase the idea, to fix all our problems we need a continuous flow of "new business models" and "technical innovations".

The Cartesian dream of prediction and control (Guimarães Pereira & Funtowicz, 2015) has led modern societies into a serious predicament: they must now endorse a dubious belief in the unlimited power of scientific knowledge, an act that has profound consequences for the functioning of the science-policy domain. The choice of policies prioritizes control over adaptability, so that an overdose of rosy scenarios is used to prevent an informed discussion over concerns.

Conclusion

First, I would like to make clear that a critical appraisal of the blunder of "circular economy" does not entail that we should reduce our efforts in recycling, reusing, and reducing. On the contrary, through adoption of a sobering narrative about our total dependence on nature—after acknowledging that the economic process is entropic—we can better understand that recycling, reusing, and reducing waste are the only strategies we have to deal with the unsustainability of the current pattern of economic growth. It is the hubris associated with the concept of circular economy—the assumption that we can substitute nature by generating our own life support system—that represents a danger to our own sustainability. In relation to this point, Giampietro and Funtowicz (2020) explain that an aggressive mobilization of expectations having the goal of colonizing the future translates into an endorsement of ideological justification narratives and a systemic suppression of criticism, thus locking in chosen normative narratives.

> Once they have attained normative status, assumptions are taken for granted, they neither must be justified nor reflected upon (*Bakker & Budde, 2012*; *Konrad, 2006*). The danger here is that the myths underpinning the

> reference points become naturalized, the result being that space for critical and hesitative reflection diminishes and it is socially discouraged (*Buclet & Lazarevic, 2014*). The all-encompassing expectations the concept brings together carry persuasive and performative power (*Brown & Michael, 2003*; *Lazarevic & Valve, 2017*). For these reasons those proposals perceived as implausible should be deemed irresponsible (*Strand, 2012*).

In conclusion, it seems safe to say that the flat Earth blunder in the sixth century was analogous to but perhaps more innocent and more harmless than the circular economy blunder of the twenty-first century. This stands true especially when considering that the quality of scientific inquiry available at the time of the flat Earth blunder was much lower. The dangerous intoxication of modern scientific inquiry in the field of sustainability can be explained by the hegemonic use of obsolete narratives endorsed by orthodox economic assumptions about the unlimited power of science and the market.

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