SeeRRI

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Description of the deliverable	As main outcome of Task 4.2 this report presents the SeeRRI Conceptual Framework, whose purpose is to help policy-makers and practitioners in developing RRI-enabled, self-sustaining R&I ecosystems addressing main societal challenges. The Framework is built on state-of-the-art systems and complexity thinking, profiting from a wide domain of concepts, presented here as the SeeRRI Thesaurus. Both the Framework and the Thesaurus are applicable to SeeRRI itself and beyond.
Key words	Conceptual framework, systemic thinking, R&I ecosystems, cybernetics, complexity, wellbeing(s) in the biosphere

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EXECUTIVE SUMMARY

This report presents the outcomes of SeeRRI Task 4.2 "Framework for a self-sustaining ecosystem", whose objective is to produce a Conceptual Framework to be used in SeeRRI itself and in other initiatives in the future. The purpose of this framework is to help policy-makers and practitioners in the system-wide deployment of Responsible Research and Innovation (RRI) in territorial contexts. SeeRRI adopts a reading of RRI beyond the adaptation of R&I processes to new formal requirements: it intends to **leverage RRI as an instrument of transformation of R&I activities to make them both self-sustaining and capable of addressing the main societal challenges**. The report includes an analysis of the current framing of R&I processes, initially established and deployed in the USA after the end of World War II, and how it has not been able to address undesirable consequences of R&I activities and outcomes. These consequences are now first-order threats to the future of humanity, including growing social inequalities, climate warming, the dramatic loss of biodiversity and the exhaustion of non-renewable resources, among others. As shown by the Covid-19 pandemic, our highly technological societies are more fragile and exposed than we thought to unexpected consequences of our actions, even coming from the most primitive of biological materials.

The SeeRRI Conceptual Framework uses a systemic perspective and state-of-the-art thinking from process philosophy, complexity theory, cybernetics and ecology, among other disciplines. Recognizing that reality is the outcome of countless ongoing processes enables a systemic approach focused on dynamic evolution rather than on static structures. This exercise builds upon established frameworks of RRI (operational and process dimensions), the EU Regional Innovation Strategy for Smart Specialization (RIS3) and the work done and results obtained in SeeRRI WP2, WP3, Task 4.1 of WP4, WP5 and WP6. SeeRRI develops its Conceptual Framework taking into account **complexity as a fundamental characteristic of our societies, challenges and goals**. All of these are dependent on the multiplicity of contexts, actors and interactions involved in R&I activities, whose evolution in a deliberate direction requires new conceptual tools. The main question addressed here is **how policy-makers and practitioners can foster in a practical way transformations of R&I ecosystems in the desired direction, without denying or betraying the complexity of the intent.**

In response to that question, two elements are central:

- A **shift of worldview towards complexity thinking** is required, both to have a better understanding of the most pressing challenges of humanity and to facilitate the task of policy-makers and practitioners in the kind of transformations envisioned;

- Transformations are **processes of mutual learning** among territorial actors working together to create the conditions for the R&I ecosystems to develop new patterns of relevance to address our existential challenges.

This report has two complementary parts:

- Sections 1 and 2 present the rationale and describe the fundamental assumptions of the Conceptual Framework, starting with Assumption Zero (adopting a process-oriented lens) and following with **Communities, Ecosystems, Interdependencies, Transformations, Wellbeing(s) in Biosphere** and **Mutual Learning**. Section 3 describes the integrated use of the Conceptual Framework in SeeRRI and the different elements deriving from it: **Set of Questions, Mutual Learnning Process, Shared Agendas, formulation of territorial challenges, and trigger processes**.

- Section 4 is a Thesaurus, i.e. a repository of 34 concepts or conceptual areas whose individual descriptions can be useful to the reader in a multiplicity of contexts. More elaborated versions are presented in an Annex. The explanation of concepts integrates academic knowledge from different disciplines as well as elements of conversations among SeeRRI partners and territorial stakeholders in workshops and meetings during the first 15 months of activity of the project. The Conceptual Framework is the current endpoint of a journey which has been collectively travelled during that period, not necessarily in a linear way. Our roadmap is represented here (see figure 1) and integrated in the report through the six parts in which the Thesaurus of 34 concepts is divided.

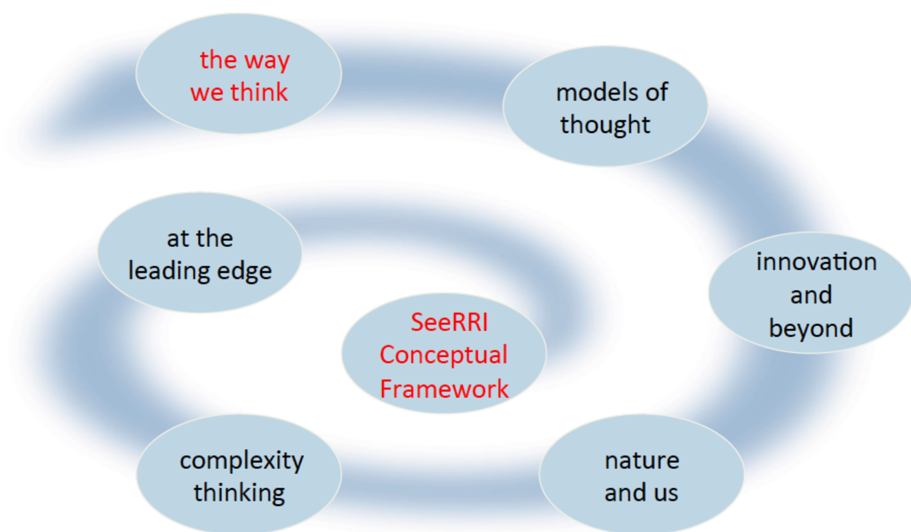

Figure 1. The spiral roadmap leading to SeeRRI Conceptual Framework (source: own elaboration)

The report closes with a brief Postface, reflecting on the context of Covid-19 and its consequences, from a systemic perspective.

1. RATIONALE FOR THE CONCEPTUAL FRAMEWORK

1.1. THE DAUNTING TASK OF POLICY-MAKERS

Nowadays the world is full of confusing signals. Humanity seems to be thriving and committing suicide at the same time. For sure, many elements of judgment are positive. Life expectancy has been steadily increasing. Literacy is slowly but surely reaching the entire humanity. Not without obstacles and setbacks, women are emancipating everywhere. For a large part of humanity aspirations to better levels of wellbeing are getting closer to realization. Science and technology are breaking barriers in our knowledge and capacity to act. To many, caring for one another is the meaning of life. At the same time, social inequalities are widening fast, political polarization and geopolitical risks are increasing, and technological innovation is also creating the possibility of dystopian futures with deeper divisions between winners and losers. Human-induced climate change and other effects of industrialization are destroying the natural foundations on which human life depends. Exhaustion of workable fossil fuels is closing an era of accessible energy with high returns. On top of all that, the impacts of Covid-19 are showing the fragility and systemic complexity of our highly technological societies: a health emergency provoked by a primitive piece of biological material is able to destabilize our whole economies, with deep social and possibly political consequences.

Responsible Research and Innovation (RRI) addresses these complex realities, and SwafS-14 combines RRI with a territorial perspective. Stating *"the **complexity of the challenges** set by the interplay between science and society"*, the topic description invokes the advantage of local actors to address *"the status quo of the **complex relationships** between cultural, social, economic and political actors, of the local dynamics, history, expectations and requirements as well as specific concerns".* In response to the challenges, *"the RRI approach (...) aims to encourage societal actors to work together during the whole research and innovation (R&I) process to better align R&I and its outcomes with the **values, needs and expectations of society**".* And *"territories can work towards the establishment of **self-sustaining R&I ecosystems** that are characterized by a high degree of openness, democratic accountability, and responsiveness to need by taking action to promote all parts of RRI"* [EC 2019] (all emphases are ours).

In the context so defined, policy-makers, practitioners and stakeholders alike face a dauting task, that of **combining three major goals** at the same time:
- promoting the deployment of RRI in all its dimensions;
- ensure that territorial R&I ecosystems are self-sustaining, and
- make R&I activities work to effectively address the societal challenges of our times.

The Regional Innovation Strategy for Smart Specialization (RIS3) offers a framework for the process of policy making, implementation and governance for public support to R&I in territorial contexts. It is represented in figure 2. A straightforward response to the task defined above is to combine RIS3 with RRI and the Agenda 2030 of Sustainable Development Goals (SDGs) [UN 2015]. The Agenda 2030 is officially supported by the European Union and its Member States, and it is the most comprehensive response to the confusing situation and challenges of humanity described above. It was established at a global level but its provisions are equally valid at all scales of policy-making and governance.

In practical terms, if one follows the philosophy of RRI (reflect, include, respond, anticipate) and takes into account the complex nature of society, all the stages represented in figure 2 are problematic:

- Is there only one context to analyze? Health, nature, economy, politics, science, technology, culture, society are all intertwined (as shown in the Covid-19 crisis), so the boundary of the area of analysis is difficult to discern, and additionally the analysis may provide contradictory conclusions;

Figure 2. The multi-stage framing of RIS3 (source: Online S3 platform)

- Formulating an appropriate strategy is a challenge in itself since our purpose is to transform R&I ecosystems so that they align with societal values, expectations and needs. Both elements of this alignment exercise are complex systems and moving targets;

- Priority setting could reveal a nightmare of entangled trade-offs: the inclusion of all kinds of stakeholders and perspectives creates a multiplicity of goals and makes frequently appear diverging interests. Economic growth used to be the priority "par excellence", but now (and for good reasons) it is only 1 of the 17 Sustainable Development Goals (SDGs);

- Policies to be implemented are also multiple and intersecting: RIS3, RRI and the Agenda 2030 can lead to contradictory injuctions, not to talk about other ongoing policies;

- Monitoring and evaluation, if performed in the conventional way, is an increasingly difficult task since it has to be multi-dimensional: e.g. the Agenda 2030 has 232 indicators. How is it possible to ensure that progress is being made when reality is so complex?

- And the governance of the whole cycle is not the smallest of the challenges in times of social fragmentation, political polarization, "fake news" and declining trust in the existing institutions.

The combination of RRI, RIS3 and the Agenda 2030 is an ambitious endeavour setting the course for deep transformations in the dynamic of territorial R&I ecosystems and in the public support they receive. In this context the above framing of RIS3 is not sufficient to provide effective guidance to policy-makers and practitioners. The role of SeeRRI is to provide a set of additional elements to address that insufficiency from a perspective consistent with:
- the complex nature of what policy-makers intend to achieve,
- the best understanding of how complex systems change,
- the potential of RRI as enabler of societal transformations.

1.2. THE SEERRI APPROACH

SeeRRI is built upon the development of three initial ideas:

- to achieve the goals described in 1.1, changes are required in the dynamics of whole R&I ecosystems: changes at the level of indidivual organizations involved in R&I are not sufficient;

- the best of knowledge is needed on complexity, ecosystems and paradigm shifts;

- changes in complex systems do not happen through a conventional approach of setting goals, defining a roadmap and establishing sets of indicators.

SeeRRI makes use of concepts grounded in decades of research in systems thinking about what "complexity" means and how "ecosystems" work. This is the intellectual driver of the SeeRRI Conceptual Framework described in this report, as main outcome of Task 4.2 (Framework for self-sustaining R&I ecosystems) in WP4 (Development and Validation of an Integrated Framework). The development of the framework is a process also fed by the analyses of the territories done in WP2 (Active Mapping of SeeRRI Territorial R&I Ecosystems), the discussions with the Consortium partners and the territorial stakeholders engaged in WP3 (Stakeholder Engagement) and WP5 (Implementing Actions), and the work done in WP6 (Impact Assessment and Activities Evaluation).

The SeeRRI Conceptual Framework enables the collective capacity to ask better questions and initiate pathways to new patterns: it is not a top-down blueprint to be applied as a recipe to get from present A to future B as if it was valid for all contexts. On one hand the SeeRRI approach integrates the fact that complex systems do not obey external injuctions and do not evolve linearly along a planned roadmap [Meadows 2002]. SeeRRI brings to RRI the recognition that its transformative role, in both R&I processes and societal challenges, is better achieved through the ignition of processes of mutual learning involving all actors and a variety of cultural perspectives (see 2.3). To that end, asking better questions is a requirement and the Conceptual Framework is a question machine (see 3.2). This is consistent with how the RRI concept itself was conceived, by questioning science, innovation and technology and unveiling our blind spots about the processes through which we acquire and develop new knowledge, and how these are framed (see 4.1).

This reflection mirrors the historical evolution of scientific paradigms [Kuhn 1962], the realization that we have entered an era of "post-normal science" [Funtowicz & Ravetz 1993] and the emergence of complexity thinking [Abraham 2002]. This is not only an academic discussion of interest to philosophers of science. In the last three centuries more than ever before, research and innovation have been extremely effective tools to transform the world around us and create the conditions for what we consider as "wellbeing". That transformative success calls for continuing the adventure of R&I

towards further progress. However, we have started realizing that progress came at a huge cost. Among many other factors, an excessive increase in the average atmospheric temperature will make human life on Earth impossible, unless we take dramatic steps. This cannot be labelled as a "collateral" effect. In a different worldview we could interpret the climate emergency as a gigantic feedback loop by the self-regulating Earth system. Reframing climate warming in that way is a good exercise to expose some of our blind spots and paradoxes: the most highly valued human capacities of science and technology are leading to the fragility and possible collapse of human civilizations, as anticipated 50 years ago by the Club or Rome [Meadows et al 1972].

The first manifestations of our self-inflicted course towards collapse have coincided with the questioning of the dominant mechanistic worldview (see 4.2). This is more than a coincidence: it is an invitation to consider other epistemologies (see 4.1.2 and 4.5) as a means to overcome the blindness of mechanistic frameworks to interdependencies and hence to most of the consequences of our actions. We know now that a big gap exists between the way we have been thinking and the way nature works. Not bridging that gap is extremely irresponsible. This opening to new worldviews also enables us to view the RRI-driven process of reframing and transformation of R&I ecosystems in a non-mechanistic way. By defining it as a process of mutual learning, it invites **all territorial stakeholders to collaborate in co-creating the conditions for the R&I ecosystems to develop new patterns of relevance to address our existential challenges**.

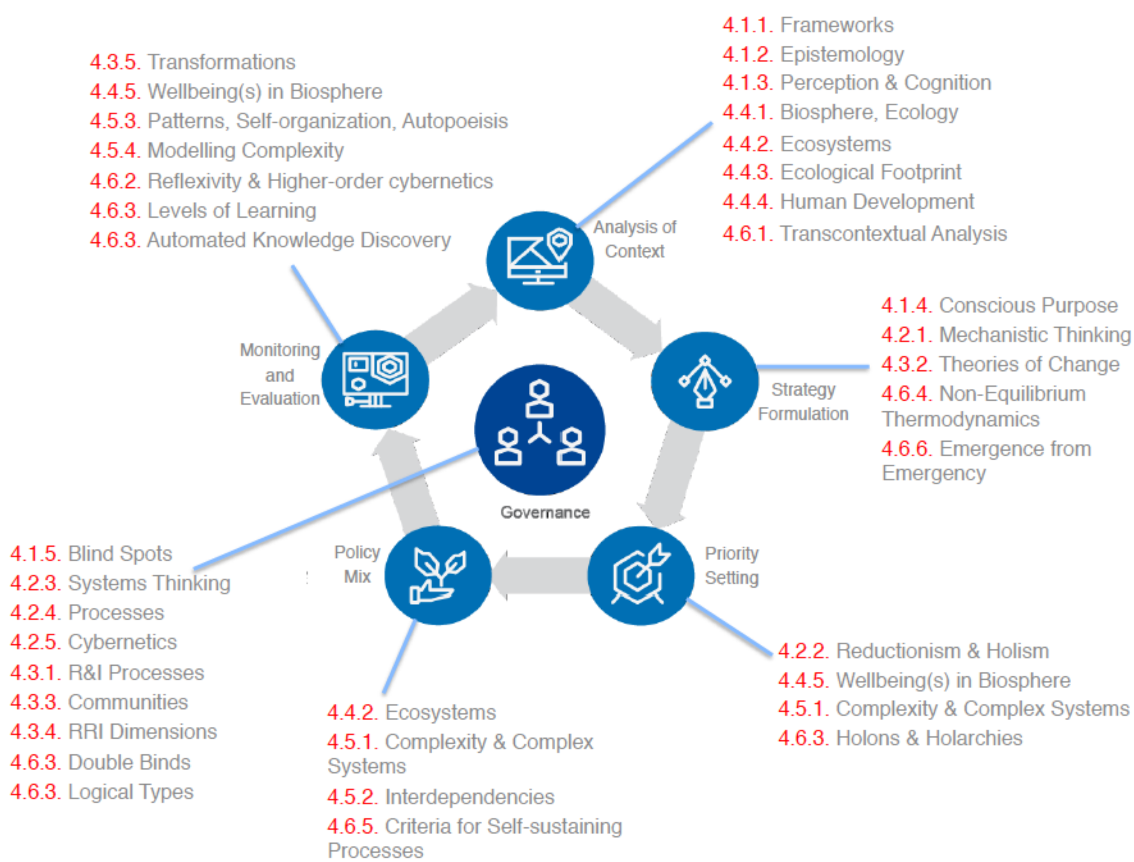

Figure 3. Relationships between RIS3 and SeeRRI Thesaurus (source: own elaboration)

In other words, the change of epistemology we need to have a better understanding of the most pressing challenges of humanity is the same required to facilitate the daunting task for policy-makers that has been described in 1.1. The SeeRRI Conceptual Framework is the materialization of that epistemological shift for the purposes of the project. Figure 3 maps the relationships between the stages of RIS3 and the many concepts and areas of knowledge inspiring the Conceptual Framework. This map complements the 6-stage framing of RIS3 and paves the way to **a substantially different way of doing, more consistent with the complexity of both the challenges and the task of combining RIS3, RRI and the Agenda 2030**. Numbers indicated in figure 3 refer to the entries in the Thesaurus (Section 4), where the concepts and knowledge areas are presented. More detailed explanations about each of them can be found in the Annex to this report.

To be clear, we are not suggesting to overload the agenda of policy-makers, practitioners and stakeholders with the task of mastering all the concepts shown, coming from so many scientific disciplines. Those concepts are the hidden part of the iceberg and need not be mastered by users of frameworks built upon them. They ensure the consistency with the state-of-the-art in systems and complexity thinking. The SeeRRI Conceptual Framework, as described in Sections 2 and 3, is the practical result to be used by whoever shares the purposes here exposed.

1.3. THE GENDER DIMENSION OF THE CONCEPTUAL FRAMEWORK

In terms of gender balance systems thinking is an unfortunately rare but positive case in the history of science. Contributions to the field by women have been significant from the very beginning and largely shaped the evolution of knowledge and agendas of research. Ada Lovelace, at the onset in the 1830s of what later became computer science, is a case in point. In the 20th century and more recent times, coming from many different backgrounds Donella Meadows, Margaret Mead, Mary Catherine and Nora Bateson, Elinor Ostrom, Isabelle Stengers, Olivia Bina, Rika Preiser, Maja Göpel, Mariana Mazzucato, Petra Künkel, Lene Rachel Andersen, Nicole Dewandre, Anne Snick, among many others, have produced relevant contributions to the large domain of systems thinking and complexity theory, making an immense impact inside and outside the boxes of their specific fields of knowledge.

Moreover, the assumptions of the SeeRRI Conceptual Framework integrate views balancing reductionistic and holistic arguments, in a way taking into consideration alternative perspectives. This echoes the process by which women have been able to become recognized in public spheres of deliberation. It is for instance noticeable that the process of shifting to the “wellbeing economy” (from which the SeeRRI assumption of Wellbeing(s) in Biosphere takes part of its inspiration) is largely led by women political leaders all around the world, e.g. in New Zealand (Prime Minister Jacinda Ardern), Iceland (Prime Minister Katrín Jakobsdóttir) and Scotland (First Minister Nicola Sturgeon). We take for granted this is not a coincidence: both the progress of systems thinking as a discipline and its impact in society are made possible by a stronger role of women in research and action. Taking into account all these circumstances we expect the Conceptual Framework of SeeRRI to resonate strongly with audiences working for a prominent role of women in leading the paradigm shift towards RRI and sustainable wellbeing.

2. SEERRI CONCEPTUAL FRAMEWORK

We present here the SeeRRI Conceptual Framework through the explicit statement of 1+6 assumptions that we assume of value for the purposes the project pursues. This is an untypical but deliberate way of elaborating a framework. The form is here in accordance with the substance. Since the recognition of the systemic nature of reality (with ourselves inside) is at the core of our approach, it would not have made sense to present a detailed blueprint for the engineered construction of RRI-inspired self-sustaining R&I ecosystems in whatever number of straightforward steps. We know that in absence of a step-by-step blueprint, the interpretation and use of SeeRRI Conceptual Framework requires the active involvement of actors in processes of mutual learning necessarily context-dependent and unpredictable to an extent. But this is what is consistent with the philosophical and methodological foundations of our approach, in our best attempt to avoid the excess of conscious purpose and to become victims of our blind spots (see 4.1.4 and 4.1.5). Section 3 describes with some detail the integrated use of the Conceptual Framework in SeeRRI and potentially beyond.

2.1. ASSUMPTION ZERO

Assumption Zero is "process philosophy" (see 4.2.4), i.e. the hypothesis that reality is the outcome of a multitude of autonomous processes unfolding in parallel over time in places, scales, and contexts, and producing structures in permanent evolution and interaction. Structures are not previous to processes, they are configurations reflecting the state of play of processes at a certain moment. These are permanently exchanging energy, resources and information with their environment, created by other processes. According to this description, there is nothing in reality which could be purely static and the persistence of processes depends on their adaptation to context. They can be contradictory with each other and all of them are engaged in the pursuit of persistence. Among different ways of adopting a systemic perspective, this one gives prominence to interdependencies (see 2.2.5 and 4.5.2) and to the dynamic character of any system, natural or human.

In this perspective, the analysis of the capacity of processes to persist is most relevant. In the context of SeeRRI it is critical to investigate how RRI-inspired processes of research and innovation can be successful in comparison with more conventional ones, as far as the dynamic of deployment of RRI is concerned. Regarding which criteria could be used to analyze the persistence of processes, and with it the possibility of self-organization (see 4.5.3), we consider the following (see 4.6.5):

- Openness: processes have to be able to exchange with their environment in order to evolve and adapt while keeping their own identity and singularity;
- Energy: processes are embodied in far-from-equilibrium dynamic entities which need to capture energy from their environment;
- Auto-catalysis: to keep the processes alive and thriving, their outcomes have to reinforce the processes themselves.

In practical terms these criteria can be translated into concrete questions regarding the processes underlying regional R&I ecosystems, especially on how transformations towards RRI can overcome obstacles (as detailed in Section 3).

2.2. BUILDING UPON CONCEPTS

We consider that a number of concepts introduced in previous sections are useful for the explicit Assumptions of the SeeRRI Conceptual Framework. The order in which we introduce them is not of high importance, all of them are equally relevant and their purpose is to frame our analysis by facilitating questions, which lead to responses and to further questions, in the endless evolutive process of mutual learning, as explained in 2.3 and further developed in Section 3.

2.2.1. Communities

This assumption states that human systems are embodied in communities of people tied together by sharing activities, traditions, practices or goals. Some of them can be more global than local (e.g. the community of performers of classical music) but most evolve in particular places and depend on local contexts. As far as RRI is concerned, there is a tension between R&I conceived at a global level, as something happening in a few places (e.g. Silicon Valley, Shenzhen), and the intrinsically local expression of societal values and needs. Historically the centres of the world-system have produced waves of innovation and modernization to which territorial communities had no option but to adapt, generally in some kind of dependency [Braudel 1979, Wallerstein 2011]. SeeRRI assumes that even if R&I activities are well connected to global trends, their local reception is critical. This is why it makes so much sense analyzing R&I processes with local and regional lenses. In this perspective, regional dimensions and policies are key for the evolution of R&I and hence (potentially) for the success of RRI. This assumption leaves out more abstract and globalized perspectives of R&I and their role. And it also stresses the importance of mobilizing communities around shared agendas and visions. In this perspective R&I processes become a resource and a capacity to achieve territorial visions, and their intertwining with local and regional dynamics and policies adopt a different meaning, as an enabler of autonomous strategies of development.

2.2.2. Transformations

We assume that RRI can become a tool to ignite processes of social transformation in an open and democratic way. The questions leading to RRI originated in Science & Technology Studies (STS) and Science in Society (SiS) programs, and in the context of SwafS the policy later evolved to promote institutional change in R&I organizations through the operational dimensions (Ethics, Gender Equality, Open Access, Public Engagement, Science Education, and Governance). Later on, by considering R&I activities in territorial contexts as whole ecosystems, RRI adopted systemic perspectives. To that end the identification of process dimensions was most useful: Reflexivity, Inclusion, Responsiveness, and Anticipation [Stilgoe 2013] are qualities of responsible processes that take into account interdependencies, a key point (see 2.2.5). Leveraging RRI as a tool for reframing the roles of science, innovation and technology in response to first-order societal challenges is an appealing next step in that evolutionary logic.

Almost a decade after the European Commission adopted the RRI policy, this assumption also responds to the *"six deficits in the global research and innovation system that constitute obstacles for innovations delivering on societal desirable objectives"* [Von Schomberg 2019]. RRI is also meant to be transformational in the sense of promoting in a differential way the success of visionary organizations and ecosystems. This leaves out the possibility that R&I ecosystems could continue "business as usual", with only minor modifications of habits. And it means as well that the learning and transformational process will have to overcome serious obstacles, and that RRI can also include abandoning certain R&I initiatives, deemed not to be responsible.

2.2.3. Ecosystems

The SwafS-14 topic to which SeeRRI responds explicitly calls for the *"establishment of self-sustaining R&I ecosystems"*. This states that R&I activities do not happen out of the blue, as if they were external to society, and are not the product of individual entities, whatever the importance of certain individuals and organizations. R&I ecosystems involve whole chains of actors and processes immersed in society, linked together through nutrient cycles and energy flows, as in biological ecosystems. Moreover, the vitality of R&I ecosystems in territorial contexts requires the participation of all kinds of actors, those directly involved in the production of R&I as well as public administrations, educational institutions, the entrepreneurial class, civil society organizations (CSOs) and citizens at large (Quadruple Helix). This approach broadens the adoption of RRI beyond approaches focused only on changes at the level of individual organizations. It also excludes the concept of R&I as something inevitable, an exogenous factor out of the sphere of societal decisions, and opens the opportunity to its reframing.

According to the characterization developed in WP2 (Active Mapping of SeeRRI Territorial R&I Ecosystems, see SeeRRI Report D2.1), territorial R&I ecosystems are by definition self-organizing and complex systems acting on a territory, defined as any area characterized by certain geographical features, or sharing cultural, environmental or economic ties. They are driven by innovation activities, co-evolution and interdependencies between different actors, from political, economic and technological scenes. As represented in figure 4, they are never static, and their dynamics are related to society, geography, economy and environment in variable contextual interrelationships, processes, and interactions. They are meant to be suited for radical innovations and niche development.

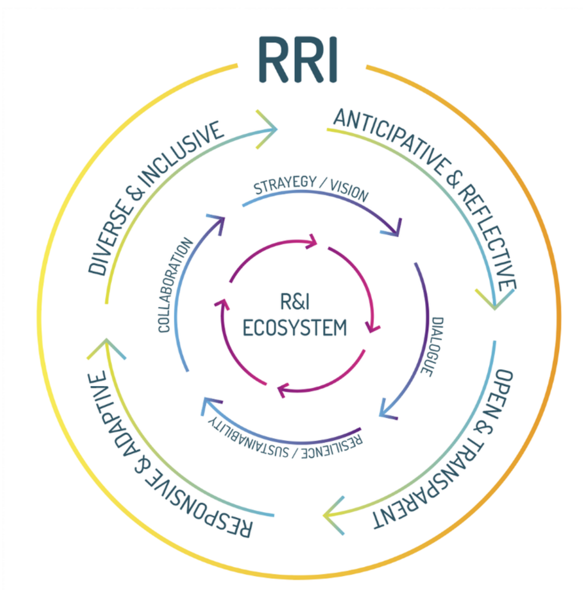

Figure 4. SeeRRI representation of an R&I ecosystem (source: SeeRRI)

According to the SeeRRI vision, an R&I ecosystem should:
- be complex and self-organizing;
- be flexible to niche development;
- find innovation potential from interfaces and unexpected combinations;
- provide platforms for development and foster peer-to-peer management;
- provide access to global business and civil society ecosystems;
- be open to innovation, co-creation and user engagement (through Quadruple Helix cooperation);
- be trial-based, experimental, and apply rapid prototyping methods in the real world.

2.2.4. Wellbeing(s) in Biosphere

We make the assumption that the aspiration to equitable human wellbeing at peace with the biosphere can be widely shared across people all around the world. For the moment it is just an aspiration. Many scientific capacities already exist to tackle the intertwined challenges of sustainability across disciplines, but the holistic perspective of reconciling human wellbeing with a healthy evolution of the biosphere has not been properly addressed yet. It is beyond the leading edge of R&I, and most R&I activities are not aligned with that purpose. At the same time, in 2020 no definition of "responsibility" can ignore the self-inflicted existential threats that humanity is facing, after Covid-19 showed the systemic fragility of our highly technological civilizations.

Addressing this gap is coherent with the assumption of transformation presented above: a deep formulation of RRI can give it a fundamental role in social transformation. This leaves out more superficial approaches to RRI, and is not just a slightly different way of performing R&I. It goes beyond the "ticking boxes" approach of compliance with a set of static rules. And it provides a framing useful at different scales. At territorial level it can mobilize local communities and groups of stakeholders around the process of elaborating a shared vision, which will be specific to each territory (as detailed in Section 3). This is why we give a plural tone to wellbeing(s), since the challenges and the responses may be substantially different from one territory to another, depending on the defining contexts and the values, needs and expectations of each territorial community. At the same time, the learnings obtained from concrete territorial contexts will be relevant to debates and policy assessments taking place at national, EU and potentially global levels.

2.2.5. Interdependencies

Human and natural systems are complex. All complex systems exhibit "emergent" behaviours, not reducible to those of their constituting parts. These, be they cells, living beings, organizations or whole ecologies, are autonomous but not independent from each other. System vitality depends on the non-trivial interactions between them. Attention has to be focused on the interdependencies between the constituting parts themselves and with other systems in their environment.

The analysis of complex systems through the lens of interdependencies is a topic at the leading edge of research. More conventional approaches have been focused on splitting the whole into parts and analyzing the characteristics of the parts, an approach sometimes described as "boxes and arrows". In the approach we propose the focus is on the interdependencies: "arrows" come to the forefront as intense relationships (see 4.5.2). This approach may look like an invitation to be overwhelmed, compared to more reductionistic options, but it also brings with it opportunities for transformation through mutual learning (see 2.3). And in its most elaborated perspective RRI is the recognition of interdependencies between R&I processes and four different aspects: the way they are conceptually framed (reflexivity), society at large (inclusion), the evolution of societal values, needs and expectations (responsiveness), the future consequences of our actions (anticipation). Putting interdependencies at the core of our Conceptual Framework helps formulating questions relevant to more than just individual actors and to understand better the dynamics of evolution of whole R&I ecosystems. It is consistent with this widely used definition of RRI by René von Schomberg:

> *“RRI is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products.”*

Adopting this particular perspective of complexity through interdependencies is also an invitation to consider the multiple contexts conditioning the particular R&I ecosystems under our analysis, since all interactions may be relevant to the behavior of complex systems. This implies that our proposals to promote RRI will necessarily depend on specific characteristics of each particular R&I ecosystem. We expect this to be a differential element favorable to the success of SeeRRI. The project considers three different R&I ecosystems in their territorial contexts (Nordland in Norway, Lower Austria and B30 in Cataluña/Spain) and several more from the Network of Affiliated Territories (NAT) with a less intensive level of analysis. Significant differences between those three territories have been observed, especially in the culture of how public debate and action is conceived. Integrating contextual information in our analysis is vital for the effectiveness of actions to promote RRI. But this statement leaves open the question of how much contextualization is needed and how to practice it.

We need to find a balance between considering all contexts imaginable and designing a practical approach to promote RRI. Many different contexts could be considered, e.g. society, geography, economy, environment, culture, history, politics, and so on. In SeeRRI we decide to use the contextualization best suited to existing frameworks of RRI such as the operational and process dimensions. On one hand, the six operational dimensions of RRI (Public Engagement, Open Access, Science Education, Ethics, Gender Equality and Governance) are used as a framework for the implementation of concrete actions in individual organizations. It has been shown that they are connected to a systemic level of analysis but in an indirect way [Snick 2017]. Addressing changes at the internal level of individual organizations does not necessarily create the optimal pathway to systemic transformations.

On the other hand, the four process dimensions associated to RRI (Reflexivity, Inclusion, Responsiveness and Anticipation [Stilgoe 2013]) fit well with the foundations of our approach. Together they are a good representation of the set of interdependencies on which the evolution of complex R&I ecosystems depends:

- Reflexivity is a requirement to address the dependency between our R&I processes and the way they are conceptually framed, in order to question them and identify what is misleading or missing,

- Inclusion addresses the need to include all types of stakeholders and society at large in all phases of elaboration of R&I processes, starting with agenda and priority setting,

- Responsiveness points to the dependency between R&I processes and societal evolution and challenges, which is insufficiently covered in existing R&I configurations,

- Anticipation is about the dependency between our current R&I processes and their future consequences.

We have then a correspondence between the concept of interdependencies at the core of a complexity-oriented systemic analysis and the four process dimensions considered as requirements for an effective implementation of RRI. This correspondence offers a pathway for our approach to combine the attributes we seek: systemic perspective and practicality of analysis. Thus we adopt it as a fundamental element of the SeeRRI approach, as depicted in figure 5.

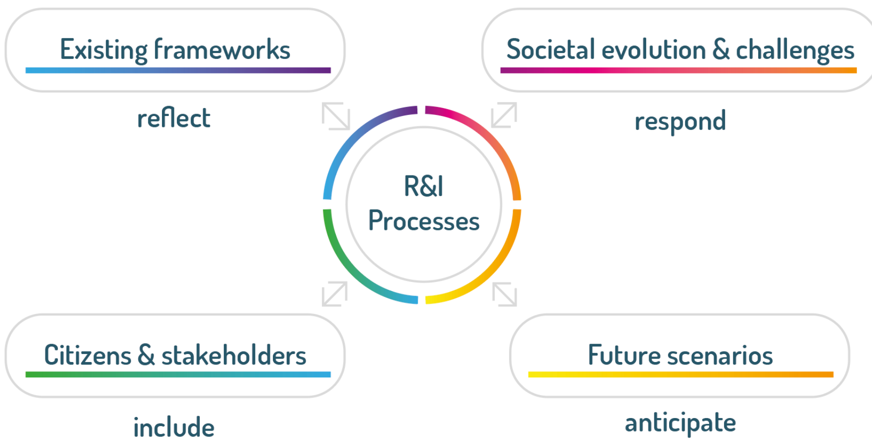

Figure 5. RRI-based interdependencies of R&I ecosystems (source: SeeRRI)

In this diagram R&I processes are represented in a central role: this mirrors the expectations of modern societies. R&I are expected to serve societal progress through the advancement of knowledge and multiple (and not necessarily coherent) attempts to provoke deliberate transformations through innovation. As discussed in 4.3, present arrangements of R&I processes do not guarantee that they are performed with the responsibility their central role requires. Systemic analysis is needed to go beyond, not as an academic exercise but as a practical way of illuminating aspects generally not considered. This in turn requires looking at R&I processes in different contexts at the same time (see 4.6.1). Figure 5 reflects the decision of SeeRRI to consider four specific contexts, directly related to the four process dimensions of Responsiveness, Inclusion, Reflexivity and Anticipation. Other relevant contexts such as society, geography, economy and environment are also present in this approach but in an indirect way, since they inform the four ones we use as primary lenses.

2.3. MUTUAL LEARNING: THE ULTIMATE PROCESS OF CHANGE

The purpose of SeeRRI is ambitious: **use RRI to enable the transformation of territorial R&I processes into self-sustaining ecosystems addressing the most pressing challenges of humanity in specific contexts**. This cannot be achieved by using a linear, mechanistic perspective. The temptation is there, though: to get it done, clarify first our final destination and then plan carefully for a succession of steps leading in a straighforward manner to the envisioned goals, while we monitor the system along the pathway to make sure that it does not deviate too much from the planning. However, there are too many examples in which this kind of planning is ineffective, even in the case of activities which should not escape from the frame: consider big infrastructure projects where everything is carefully planned beforehand but there are too many interdependent factors and then everything results in long delays and budget overruns.

With complex systems the planning method is simply misleading: to start with, the actors in charge of transformation are not external observers, they are themselves part of the system they would like to transform. They cannot adopt an external position from which they could analyze "objectively" the territorial R&I ecosystems of which they are part and transform them through the injunction to adopt certain practices. And the evolution of complex systems is based on endless chains of actions and reactions, questions, answers, more questions and feedback loops with the potential to ruin any deliberate intention, to produce "collateral effects" counteracting the original goals.

This does not mean that it is impossible to achieve purposeful change in a complex system. Complex systems can change and evolve by learning to develop new patterns in order to adapt to a changing environment. Hence, the question about change becomes how to create the appropriate conditions to ignite that learning process. We cannot plan either the modifications of the conditions in order for the system to change exactly in the direction we desire. **The process of creating learning in a complex system is itself a process of learning, and of mutual learning in interaction with the system**. This is a fundamentally different approach compared to the planning strategy. It has to proceed stepwise, be flexible and agile, and take into account the interdependencies and contexts in which the system is evolving as much as possible. There is no way to guarantee that all factors and interdependencies are taken into account. So, there is no perfect recipe for the learning process of making complex systems learn something different from what they are used to. If there was a recipe it would not truly be a learning process. In other words, transformation towards RRI and the SeeRRI project itself are exploratory processes, learning adventures in which we do not know in advance what or how we are going to learn. This is the way that complex systems can change, not by “teaching” them predefined recipes from the outside but rather by creating the appropriate conditions for the actors within the system to start thinking differently and creating pathways towards a shared vision.

It also follows that monitoring the evolution of a complex system cannot proceed with the usual techniques for impact measurement. Decomposing the overall change of behavior into a list of piecemeal indicators may miss the holistic nature of spontaneous reorganization into different patterns. If we recognize complexity in the systems we would like to change, we should not pretend that strategies framed in mechanistic thinking will work. We should rather optimize our strategy for the learning process to succeed. First, by understanding that it is a learning process, not a planning one. Second, by having a wider consideration of the interdependencies and contexts which are relevant to the evolution of the system. As discussed in 4.3 and 4.4 the current framing of R&I ecosystems make them largely blind to the consequences of all their outcomes; moreover, some of these are undesirable or even create existential threats. We also consider that RRI is a good starting point for a more holistic and sensible framing.

Figure 6. Circular process of mutual learning (source: SeeRRI)

Figure 6 proposes a graphical representation of what a circular process of mutual learning could look like, starting each cycle with a reformulation of the general criteria informing every step: at the more general level the criterion is "Wellbeing in Biosphere", but this means different things in different territorial contexts (see 3.3). Then concrete challenges can be identified and responses designed, implemented and checked against the design criteria, and so on, since each cycle is not a step toward a final solution but rather a step upward in the ladder of mutual learning into a different state of the overall system. Commmunities and the biosphere are represented at the center to express the criticality of their role in the development of territorial pathways towards sustainable wellbeing.

3. INTEGRATION AND USE OF THE CONCEPTUAL FRAMEWORK

3.1. THE CONCEPTUAL FRAMEWORK IN SEERRI

As discussed in 4.1.1, there are good reasons for SeeRRI to develop a new Conceptual Framework. Its purpose is related to the deployment of RRI philosophy and policies and the transformative potential of R&I ecosystems in territorial contexts. To that end a certain way of thinking, derived from the realization and acceptance of complexity, has been adopted. Section 2 describes the work of construction of the Conceptual Framework through the explicit identification of its fundamental assumptions: they are different from those used, conciously or not, in other conceptual frameworks. The exercise of making explicit the assumptions is itself a substantial difference, since this is not often done in the literature on innovation and social transformations. The assumptions selected in our case come partially from the fundamentals of our approach, described in Section 4, and also from the RRI-based contextualization of territorial R&I ecosystems (see 2.2.5). Table 1 shows how the Conceptual Framework and its six fundamental assumptions originate in the intellectual foundations and in the contexts used in our analysis. Assumption Zero is the idea that processes, rather than structures, are central to the description of any kind of system (see 4.2.4).

Foundations	Contexts	Conceptual Framework
Epistemology, cognitive science		Need of a new framework
Process philosophy		Assumption Zero
Analysis of R&I Processes		Ecosystems
Complexity		Interdependencies Mutual Learning
Process Dimensions of RRI		Interdependencies
	Existing frameworks	The whole set of CF assumptions
	Societal evolution & challenges	Wellbeing in Biosphere
	Citizens & stakeholders	Communities
	Future scenarios	Transformation

Table 1. Elements of SeeRRI Conceptual Framework (source: own elaboration)

The assumptions are useful to create common understandings among the partners of the project and as a consequence to give consistency to the activities with the stakeholders in the territories, during and beyond the project itself. The Conceptual Framework is also a generative tool, a process by which a certain number of relevant questions are addressed. This embodies a conception of how complex systems change, through iterative processes of mutual learning under appropriate conditions, an idea which is useful in any circumstance, within and beyond the project. A more traditional approach could have been based on a linear linking between cause and effect, as depicted in figure 7:

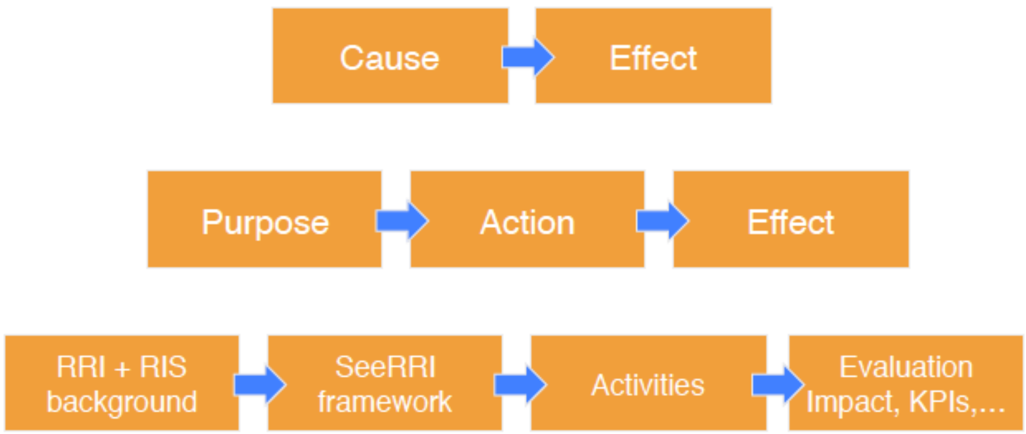

Figure 7. Linear ways of framing (source: own elaboration)

This traditional approach was also an option for SeeRRI: it would have defined an explicit roadmap to go from a certain state A to a desired state B in a number of steps, as well as certain manner of monitoring how progress is made along the pathway. As discussed in 2.4, this is not incorrect in itself but is at least incomplete (and can be misleading). It presupposes that we can observe the systems to be analyzed and transformed from outside (the regional R&I ecosystems) and that we can modify them through the injunction to adopt certain practices. While this may be effective to a certain extent, our theory of change acknowledges that complex systems learn by themselves when exposed to appropriate conditions. Their processes will adapt and make sense of the new context in patterns different from those existing before. They will respond to new questions, and the responses will lead to new questions, and so on, as depicted in figure 8.

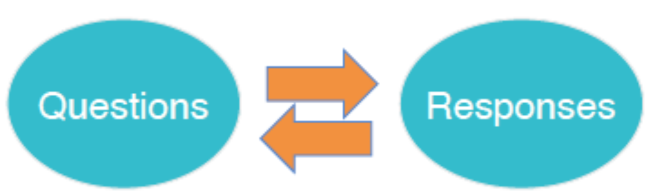

Figure 8. Dealing with complex systems (source: own elaboration)

With this perspective in mind, the process of construction and use of the Conceptual Framework is substantially different, it is already part of the process of Mutual Learning of the project (and beyond). As represented in figure 9, it integrates a number of inputs coming from different sources, including state-of-the-art in systems thinking and innovation (as described in Section 4) but also lessons learned from other RRI projects and relevant findings from other Work Packages in SeeRRI.

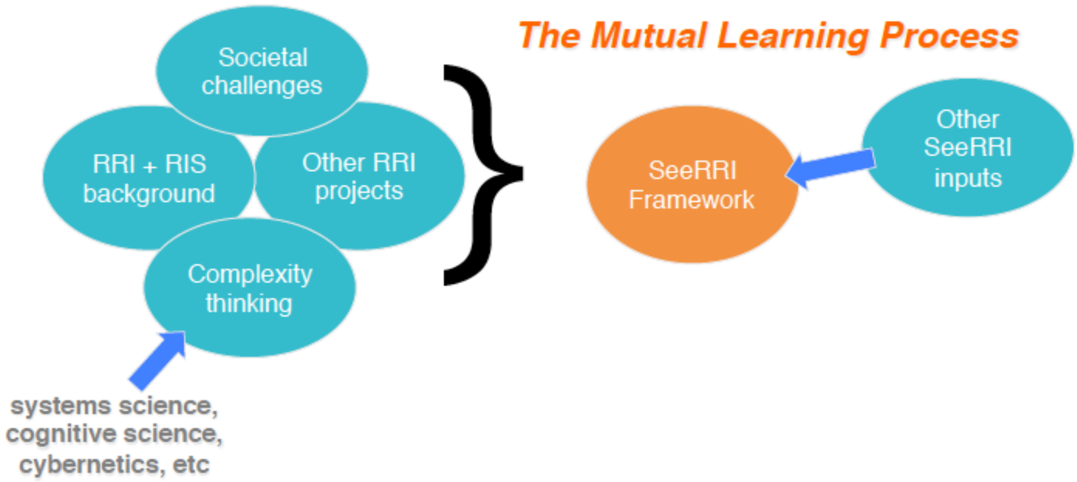

Figure 9. Mutual learning starts with the construction of the framework (source: own elabotarion)

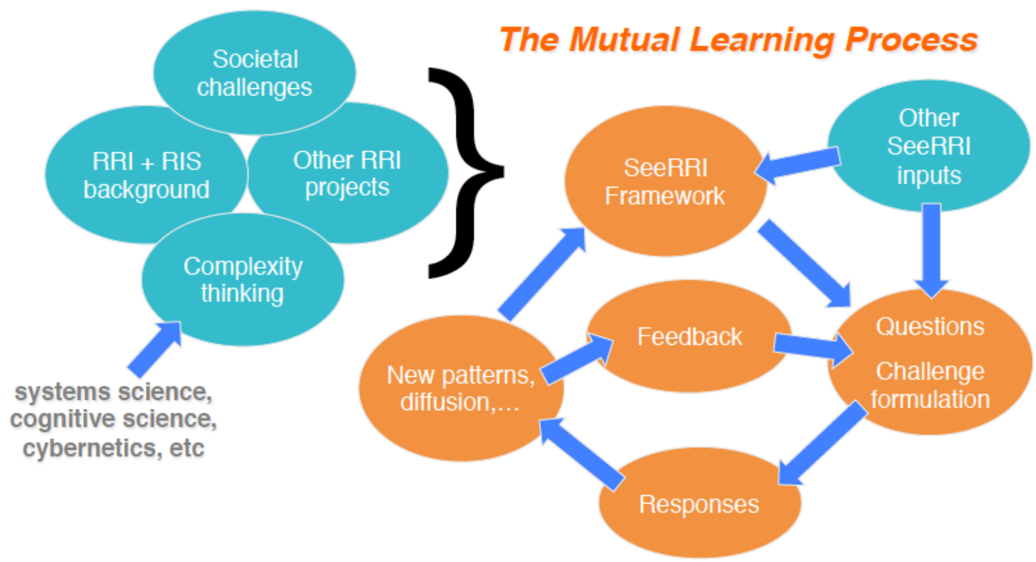

Figure 10. Circular use of the Conceptual Framework (source: own elaboration)

The use of the Conceptual Framework implements the circular logic of an iterative process, as described in figure 10: it structures a systematic way to ask questions. It can be understood as a question machine providing inputs to the mutual learning process and helping the stakeholders to formulate their challenges in a specific and context-dependent manner which is easier for them to adopt than more general and abstract ones. For those questions to be effective in the development of the relationships with SeeRRI stakeholders, they have to be:

- Easy to understand in stakeholders´ specific contexts,

- Relevant to the purpose (aligning R&I processes with RRI in regional contexts),

- Relevant to the intermediate purposes and visions developed by the stakeholders in the project,

- Not trivial, so that the responses can generate new and fruitful perspectives.

The Conceptual Framework does not ensure all this in an automatic way, but it helps the partners to engage in meaningful conversations around relevant questions. For this to happen, the stakeholders do not have to be necessarily aware of all the assumptions and details of construction of the Conceptual Framework. It does not need to be presented to and validated by them, it can actually be kept relatively hidden while producing questions which are useful for the mutual learning process, as described in figure 11.

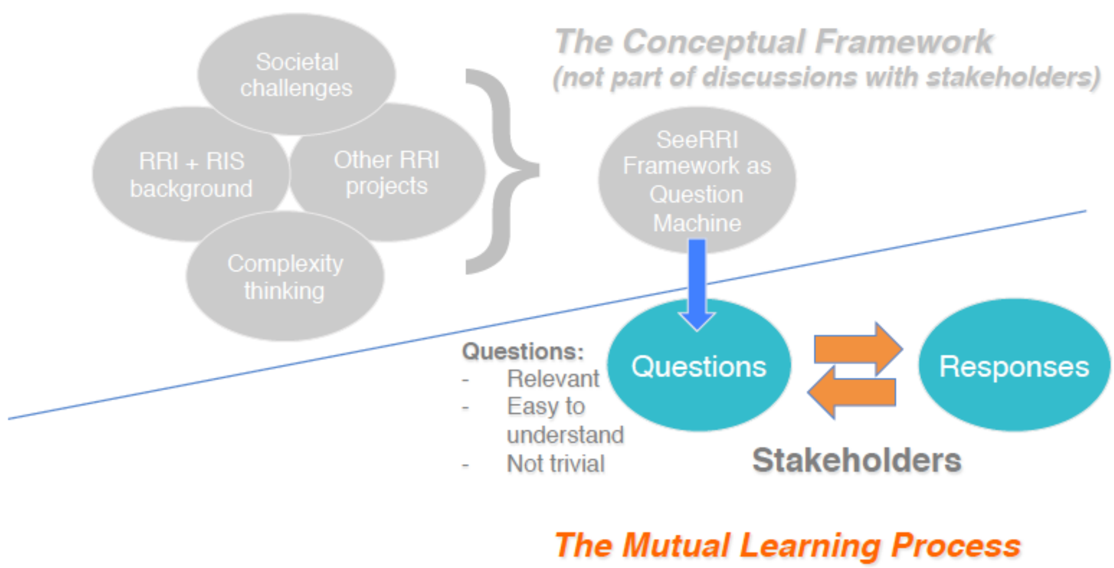

Figure 11. Involvement of stakeholders in the Mutual Learning Process (source: own elaboration)

The explicit assumptions of the Conceptual Framework facilitate a consistent execution. They are a guiding reference to:

- Orient and align the questions asked and hence the learning acquired with the overall and intermediate purposes of the project;

- Identify not only the questions to ask but also those which are most relevant to the general dynamic of transformation;

- Ensure that relevant aspects are not missed (especially by applying the criteria for self-sustaining processes described in 4.6.5);

- Prevent significant blind spots from blocking the process of learning and transformation.

It follows from this that Work Packages WP3 (Stakeholder Engagement), WP4 (Development & Validation of an Integrated Framework) and WP5 (Implementing Actions) have to work in close coordination, especially as far as the activities with stakeholders are concerned. This implies working together particularly on the questions and activities derived from them. This is ensured by the existence of the WP Task Force as a team working with a common understanding of the goals and activities of the three Work Packages. In practical terms, the WP Task Force works together in defining:

- An agreed set of questions to be addressed with the territorial stakeholders,

- A draft of list of activities to be proposed to the stakeholders and later refined.

Figure 12 presents a graphical interpretation of how the Conceptual Framework works in the overall context of the project and of the interactions between the WPs and with the territorial stakeholders. The label of "SeeRRIzation" is just meant to be provocative, for communication purposes.

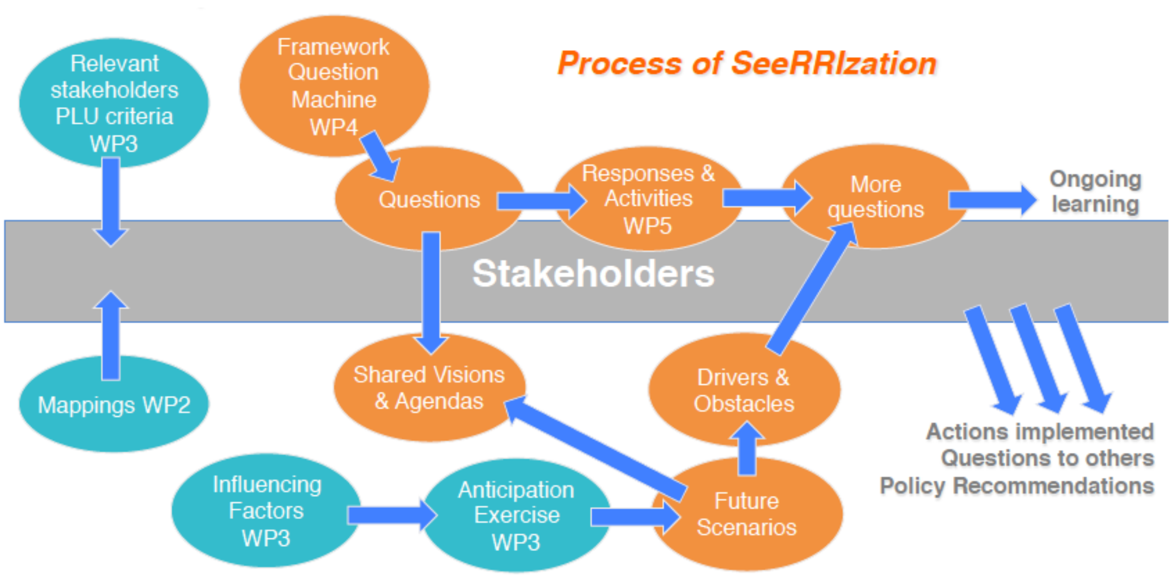

Figure 12. Overall process within SeeRRI Work Programme (source: own elaboration)

Regarding the implications in terms of goals and outcomes of the three WPs, this elaboration of the Conceptual Framework does not modify substantially what was already defined in the initial SeeRRI Work Programme. The Conceptual Framework accommodates the different inputs from the different WPs as originally planned. It requires a close coordination between WPs and has been enriched by the ongoing conversations with the territorial stakeholders, which is consistent with the approach of mutual learning.

3.2. SET OF QUESTIONS AND ENGAGEMENT PROCESSES

This subsection collects an initial set of questions derived from the construction of the Conceptual Framework and the processes by which the territorial stakeholders have been engaged since the beginning of the project. Formally the engagement has been part of WP3 but WP3, WP4 and WP5 are working in close coordination, in order not only to maintain consistency but also to make the best use of the interactions with the stakeholders, who have the leading roles in the transformation of the territorial R&I ecosystems. Questions are presented here together with the mention of the Conceptual Framework assumptions from which they are derived and in which manner they are being addressed in the project. All questions are formulated as addressed to territorial stakeholders.

Assumptions "Transformation" & "Wellbeing in Biosphere"

Question #1: *Can you imagine something like the process depicted in figure 13 happening in your territory, with "Wellbeing in Biosphere" being the main design criterion?*

Figure 13. RRI-based self-sustaining R&I ecosystem (source: own elaboration)

Assumptions "Transformation" & "Wellbeing in Biosphere"

Question #2: *What could be the initial formulation of challenge in your territory, which would be meaningful and concrete enough to mobilize a wide community of stakeholders?*

This question has been addressed in WP3. The phrases below summarize the more elaborated responses (see 3.3):

- Niederösterreich: "Decarbonization of the plastics industry",

- Nordland: "Sustainable management of natural resources",

- B-30 (Catalunya): "Zero Waste".

Assumptions "Transformation", "Communities" & "Mutual Learning"

Question #3: *In your territory, who should be concretely mobilized around the main challenge and the corresponding vision? How can alliances be built to ensure the challenge is properly addressed?*

Responses to these questions are being elaborated as part of WP3. The identification of relevant stakeholders is complete, as well as their screening according to the PLU criteria (Power+Legitimacy+Urgency). A process for building shared agendas and ensuring engagement of stakeholders is also being developed in WP5.

Assumptions Zero, "Transformation", "Interdependencies"

Question #4: *How can we convince territorial stakeholders that RRI is in their interest? In particular, how can we convince a business that RRI makes sense as an element of its strategy?*

The first elements to elaborate responses to this question come from the identification of Influencing factors (in WP3, see 3.4), as inputs to the strategic reflections of the territorial stakeholders. Most probably some of the responses will point to factors out of the domain of direct influence of the stakeholders, and can lead to policy recommendations, later on in the project.

Assumptions Zero, "Transformation", "Communities", "Interdependencies"

Question #5: *How will the SeeRRI vision impact on important characteristics of existing R&I processes? In particular,*

- *how does a community-centered vision fit with the global connections of existing processes (the "glocalization" factor)?*
- *how does the Open Access orientation of RRI fit with existing arrangements on patents and their exploitation?*

This question is related to two aspects determining the shape of local R&I ecosystems in a global context. In many cases (especially in Niederösterreich), local R&I ecosystems are parts of larger, globally defined networks: their operating mode responds to the demands of a globalized industry (such as plastics) and their direct connection with territorial challenges of Wellbeing in Biosphere is somehow indirect (other than providing high-quality jobs). In this sense, being locally responsible may not be sufficient to make the global process responsible (again, a relevant question for the global plastics sector of which Niederösterreich R&I processes are part). The second aspect of the question is related to Intellectual Property (IP) and its relationship with the Open Access dimension of RRI. In the case of globally-inserted territorial R&I ecosystems, IP is a fundamental factor of the business model of many stakeholders. This question has not been fully addressed yet, it has to be developed in conversations with the territorial stakeholders.

Assumptions Zero, "Transformation", "Interdependencies"

Question #6: *How will RRI impact the "metabolic flows" of existing R&I processes? By such we mean:*
- The capture of funding and revenue streams,
- The attraction of talent,
- The creation and capture of new knowledge.
Will RRI make a positive difference on these?

The vision and implementation of SeeRRI require creating new processes or modifying existing ones according to RRI principles. This question is fundamental for the analysis of the sustainability of these new / modified processes. This question has not yet been addressed in detail.

Assumptions Zero, "Transformation", "Interdependencies"

Question #7: *How could it be ensured that RRI processes are more successful than those who do not consider the importance of RRI?*

Together with Questions #4 to #6 above and Question #8 below, this is the heart of the matter (from a complexity perspective based on process philosophy). If conditions are not created to ensure that the kind of processes we would like to see thriving in an R&I ecosystem have an easier pathway to success than those who do not accept RRI, the whole dynamic of the R&I ecosystem will impede the effective deployment of RRI. Some elements of a response can come from the identification of Influencing factors (from WP3, see 3.4). But systemic factors need to be considered, many of them out of the domain of influence of stakeholders. This will probably lead to policy recommendations at a later stage of the project.

For the moment we have already elaborated a first identification of structural factors that could drive the deployment of RRI in existing R&I ecosystems. At the level of abstraction at which it is defined this identification of factors pretends to be reasonably exhaustive and comprehends perspectives coming from different "theories of change" (see 4.3.2):

State-driven perspective:
- Regulatory enforcement of RRI
- Changes in public procurement towards RRI-compliant providers

Market-driven perspective:
- New opportunities derived from RRI
- Changes in customers´ habits and preferences
- Differentiation through reputational benefit of being RRI-compliant
- Differentiation through quality effects of being RRI-compliant
- Differentiation through cost effects of being RRI-compliant

Co-creation:
- Large scale pro-bono involvement of citizens in RRI activities
- Opportunities difficult to address by non-RRI organizations (e.g. because citizen science is critical)

Cultural change:
- Widespread adoption of a new cultural norm

With this in mind we collected some qualitative evidence. In September 2019 a Questionnaire was submitted to participants in the project as part of WP6 (Impact Assessment and Activities Evaluation). Some of the questions were related to elements of the SeeRRI Conceptual Framework. In particular, respondents were asked to score with "Yes" or "No" the following options, if they considered them or not as factors potentially contributing to the deployment of RRI:

- ❑ Top-down institutional pressure (through mandatory requirements, policies, regulations, etc)
- ❑ Ecosystem emulation (because relevant actors have been successful by adopting RRI)
- ❑ Opening of new opportunities (because RRI brings new opportunities to address, new research topics, new needs for innovative processes and products, etc)
- ❑ Competition on quality (because RRI enables differentiation at global level, higher-quality processes or products, etc)
- ❑ Competition on costs (because RRI enables more efficiency in processes, use of resources, etc)

- ❑ Bottom-up pressure from society (because citizens / consumers are strongly demanding RRI)
- ❑ Emergence of new forms of R&I from failures of previous ones (e.g. through radical "citizen science" because "traditional" R&I is not helping in addressing societal challenges, e.g. SDGs)
- ❑ New cultural norm (because not adopting RRI has simply become inconceivable)

The Questionnaire was answered by 39 persons from all SeeRRI Consortium partners (for anonymity reasons we are not able to distinguish which answers come from which territory). The results are presented in figure 14, which shows the differences between percentages of "Yes" and "No" for each of the mentioned options. Responses are somehow worrying, since only two factors get significant acceptance (more "Yes" than "No") and in both cases only by 28% of difference. So, it seems that only top-down pressure through legal enforcement and regulations, and the existence of new R&I opportunities directly brought by RRI are seen as favourable factors to promote RRI, and even those are not very positive. Competition on quality is also retained, but with only 8% of positive difference. This is in contrast with the strong consensus that cost considerations will not help RRI (negative difference -84%) and that new forms of R&I will not play a relevant role (difference -64%).

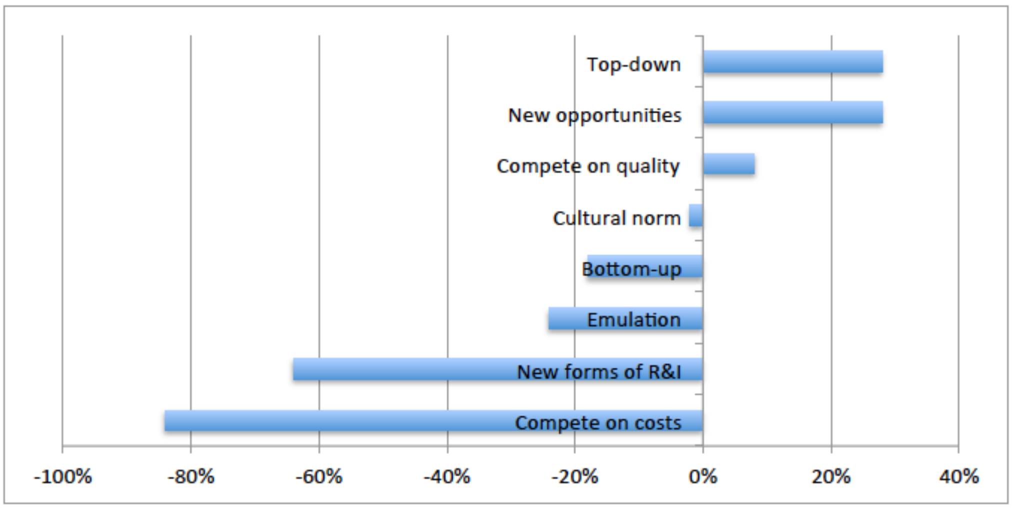

Figure 14. Assessment of factors driving the deployment of RRI (source: SeeRRI)

Looking at the same structural issue from a different angle (partially covering Question #6 above), we take for granted that RRI will not be deployed in a systemic way if RRI-compliant processes and organizations do not attract more resources than those not caring for RRI. Resources can be revenues but also volunteer time and other forms of contribution. To analyze this, respondents were asked to score with "Yes" or "No" which of the following factors would be decisive in improving the resource base of organizations committed to RRI:

- ❑ Regulatory enforcement of RRI
- ❑ Changes in public procurement towards RRI-compliant providers
- ❑ Changes in customers´ habits and preferences

- ❑ Differentiation through reputational benefit of being RRI-compliant
- ❑ Differentiation through quality effects of being RRI-compliant
- ❑ Differentiation through cost effects of being RRI-compliant
- ❑ Large scale pro-bono involvement of citizens in RRI activities
- ❑ Development of opportunities difficult to address by non-RRI organizations (e.g. because co-creation is critical)

The results are shown in figure 15. Again, substantial scepticism appears on almost all factors, which is somewhat troubling. Only regulation gets a strong backing (+58%). The correct interpretation of both assessments is not easy, but at the very least we could say that respondents do not perceive the conditions for many structural factors to help in the acceleration towards a wide deployment of RRI.

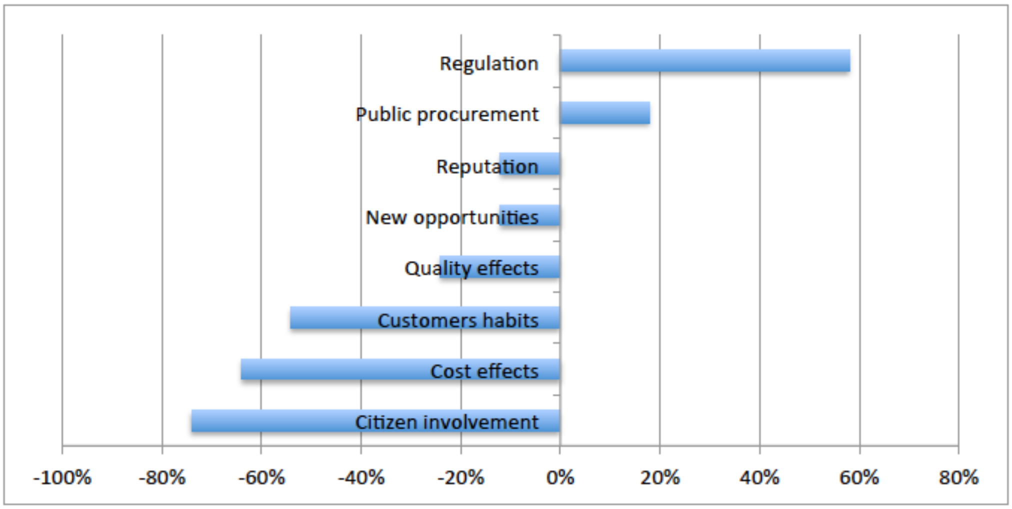

Figure 15. Assessment of factors increasing the resources for RRI organizations (source: SeeRRI)

This issue of which structural factors could or will help to the deployment of RRI has to be further developed in conversations with the territorial stakeholders.

Assumptions Zero, "Transformation"

Question #8: *How do we ensure that RRI processes are self-reinforcing?*

As discussed in 4.2.4 and 4.6.5, as a general criterion for the sustainability of any process it is critical that the outcomes of RRI-enabled R&I processes give a positive feedback (of any kind) to the processes themselves. They should contribute to improve / expand the capacities of the processes (in a similar way as economic benefits expand the capacity of the company producing them). This question has not been addressed yet.

Assumption "Interdependencies"

Question #9: *How do we reflect on future consequences of R&I activities?*

This question is being addressed through the Anticipation Exercises being developed in WP3, which are identifying Future Scenarios, both of desirable and undesirable developments. These can be used as references for developing the reflection.

Questions coming from Framework Assumptions

The 9 Questions identified above do not exhaust the list of what has to be questioned under SeeRRI Conceptual Framework. The purpose of the initial Set of Questions is not to be exhaustive, it is to ensure that the questions are relevant to the overall purpose of SeeRRI (and of RRI at large), and useful to engage territorial stakeholders into motivating and fruitful conversations. The active inclusion of stakeholders and citizens at large is one of the key aspects of the deployment of RRI and it is by far the most difficult. It is disruptive of existing R&I processes which were not originally conceived for wide consultation and engagement. The degree to which this is achieved depends on at least two dimensions. The first dimension concerns which phases of R&I processes are open to inclusion. A second dimension concerns the audiences to which R&I processes are open. It is natural to involve public administrations and business representatives, but less natural and more difficult to mobilize citizens at large.

Several activities in SeeRRI are intended to address these issues. The mappings produced by WP2 (Active Mapping of SeeRRI Territorial R&I Ecosystems) identify in detail the stakeholders involved in R&I processes in each of the three SeeRRI territories. This was done at two levels: the evaluation of the participation of different sectors, research organizations, educational institutions, businesses, governments and other actors (e.g. consulting companies). The mappings also identify the most relevant actors at the level of concrete organizations participating in R&I processes. This exercise provides valuable information to WP3 (Stakeholder Engagement), which in turn is focused on ensuring that the perspective of SeeRRI is co-created with the stakeholders, among other means by practicing Anticipation Exercises with them.

Regarding the involvement of citizens at large, the question remains open on how to achieve that goal, which may mean many different things, from a basic level of open consultation to stronger involvement through "citizen science" projects or even an actual co-creation with citizens of the agendas for future R&I activities. What is feasible and appropriate in terms of citizen engagement remains dependent on territorial specificities and in particular on the different cultures for public debate and decision-making. In this respect, Austria, Norway and Spain have quite different histories and practices, which are relevant for the contextualization of this dimension of RRI. Such differences are being revealed in practical terms in the development of the activities of the project itself, especially in WP3 and WP5.

3.3. SHARED AGENDAS AND FORMULATION OF CHALLENGES

Questions #2 and #3 above express the need for an effective manner of engaging territorial stakeholders and for that engagement to have the widest impact on the transformation of territorial R&I ecosystems. To ensure that both needs are properly addressed some kind of guidance is required. This is consistent with the process dimensions of RRI and the systemic analysis developed in previous sections. If evolution is a process of mutual learning rather than the execution of a deliberate plan, one needs to learn how to learn together with the communities involved. This necessitates the development of new approaches since the traditional mechanistic ones will be inadequate. With this in mind, the Generalitat de Catalunya with the support of Universitat Autonoma de Barcelona (UAB), have elaborated a methodology around the concept of "Shared Agendas". The mobilization of stakeholders is expected to be more effective if they are actors in the creation of shared visions of the future and the present and in the construction of shared agendas of transformation ultimately leading to systemic impact towards the shared vision (see figure 16, [GenCat 2020]).

This approach provides a way to get responses to Questions #2 and #3, and #1 as well. It helps to identify a vision which could be widely shared, initially expressed as a simple slogan without much detail. The slogan can be used to start initiate a learning curve. In the case of B-30 it was done at an early stage of the SeeRRI project: "Zero Waste" was the slogan adopted, a radical vision of circular economy at its best. While it is probably impossible to implement in its entirety this is not critical since the strength and simplicity of the slogan is good enough to open mindsets and mobilize actions.

The concrete manner in which engagement is achieved must be specific to each territory, whether in SeeRRI or beyond. The situations in Austria and Norway are substantially different:

- In Niederösterreich, the focus is on the evolution of an industrial sector, which was deliberately set up with the strategic intention by the public administration to increase the specialization and competitiveness of the region at a global level. Nowadays, the challenge is the dependence of that cluster on some specific industries (e.g. plastics) whose role is being questioned in the light of sustainable development. In this case, engagement is related to the reorientation of an industrial strategy, which has been successful so far, but now faces untypical challenges of low intensity but potentially dramatic consequences (like reputational risks linked to plastics). Maintaining a significant level of high-quality employment is one of the main issues.

- In B-30, the government itself (Generalitat de Catalunya) creates a new context through its intention to give a different meaning to RIS3 policies. By deliberately adopting a systemic and holistic perspective, GenCat is promoting the emergence of a new space for engagement in which there is a community-oriented perspective and a strong emphasis on sustainability and circular economy through the "Zero waste" slogan. This involves the (far from trivial) construction of a new process involving local administrations, the business sector, NGOs and associations, and academic institutions in an unprecedented attempt to explicitly co-create desirable futures.

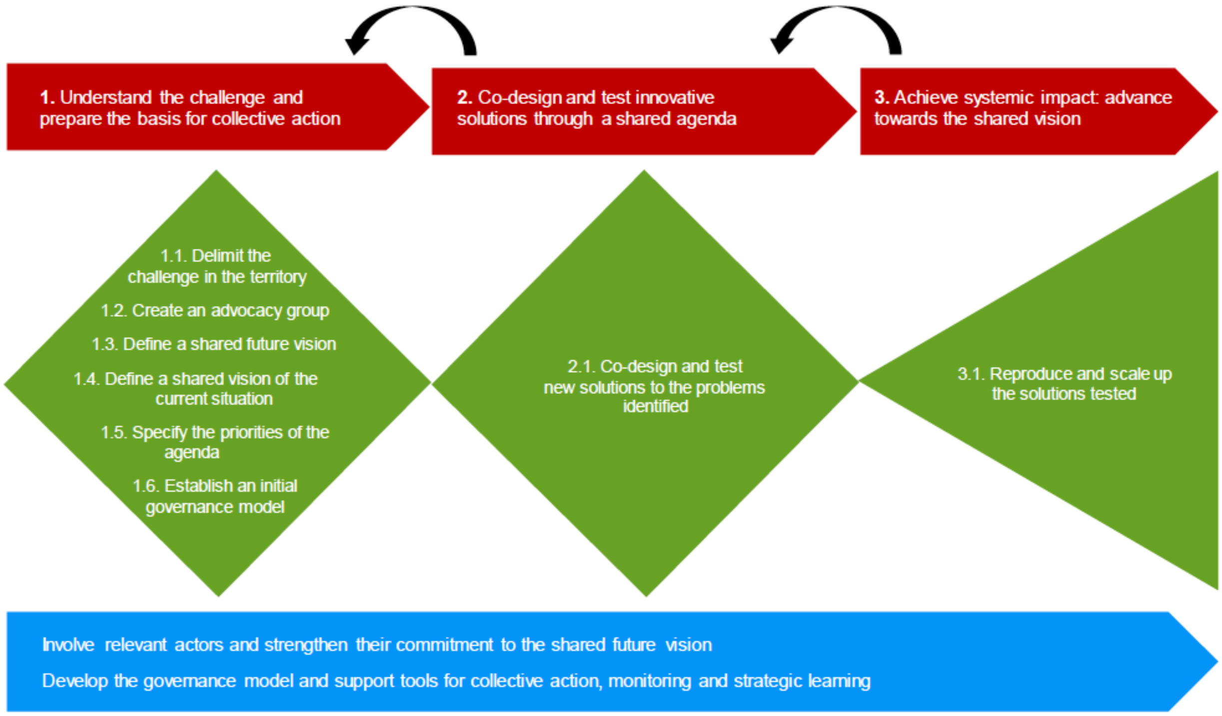

Figure 16. The development of Shared Agendas in 3 steps (source: GenCat)

- In Nordland, a strong tradition of deliberation and consensus is part of the local culture. Moreover, the entrepreneurial spirit and the balance between wellbeing and the health of the biosphere are well established. Regional planning needs to be agreed between the regional government and the 42 municipalities with legal capacity on land use because legal authority is distributed. The challenge is how to inject new tools and methods into the process of building the next Regional Agenda, to address the sustainable management of marine resources over a large and low-density coastal area, as well as the deployment of wind energy in a practical manner.

In all cases, perceptions obtained from the series of workshops with stakeholders indicate that SeeRRI activities are useful in creating or increasing the degree of engagement. This does not necessarily unfold in a completely straightforward manner, but it happens. In the discussions among stakeholders, these express positive feelings about their involvement in co-creation and in the collective elaboration on territorial challenges.

The way in which each territory describes and formulates the challenges it faces and how these can be addressed by their own R&I ecosystems is fundamental to the purposes of SeeRRI. It is a good synthesis of many different aspects analyzed through all four RRI-based contexts discussed in 2.2.5. Since such formulation did not happen at the very beginning of the project (except to an extent in the case of B-30), this created the opportunity for leveraging knowledge discovery and open discussions before jumping too rapidly to conclusions.

In SeeRRI, the formulation of challenges is an ongoing process through which aspects of the four contexts (Existing Frameworks, Citizens and Stakeholders, Societal Evolution and Challenges, and Future Scenarios, see 2.2.5) are made visible and influence the questions being asked. Such an evolution at the level of reflection facilitated by SeeRRI is made evident by the adoption of Thematic Foci at the territorial level, two of which did not exist or were not clearly formulated when the project started.

As part of the preparatory work for the SeeRRI Project Meeting with the Territories in Barcelona on 13/2/20, an explicit formulation of challenges was elaborated, which we report here. It includes SeeRRI territories and four additional cases participating in the Network of Affiliated Territories (NAT).

ecoplus (Niederösterreich) (SeeRRI partner)

Challenges: The sectorial R&I ecosystem of plastics currently faces several challenges. Plastics contribute a lot to securing the standard of living we are used to today. However, the plastics industry suffers from a very poor image in society and politics, caused by the global discussions on plastic waste. Therefore, several problems are becoming more and more apparent. Among them, there are no longer enough qualified employees and the influx to plastics education is decreasing very strongly. Who would like to start a professional future in a sector threatened with being banned?

The plastics R&I ecosystems develop and produce high-tech products for all aspects of our lives, textiles, food industry, healthcare, household, construction, mobility, energy, infrastructure, etc. Which measures are now required to improve the image and knowledge of plastics in the population in order to establish a correlation with many positive aspects? Considering the RRI approach, how can we develop a strategy in order to obtain the following results?
- Become aware and face the current situation,
- Repair the damage caused by plastics products and waste, by developing specific concepts for this,
- Make attractive a successful plastics industry with high intensity of R&I activities,
- Develop a happy image of the plastics industry that creates many positive feelings, and
- Develop approaches to create attractive jobs with a focus on women.

Thematic Focus: In the future, the plastics industry in Lower Austria will make significant contributions to achieving a **climate-neutral, environment-friendly and resource-saving economy** through its research, developments and products taking into account the entire added value at a global level.

B-30 (Catalunya) (SeeRRI partner)

Challenges:
- To change the current production and consumption model to one based on green and circular economy in order to capture the potential social, economic and environmental benefits of this transformation, benefiting from local resources and articulating effective responses to socio-economic problems in the territory. Within this shared framework, the SeeRRI project focuses on the challenge of promoting the transition of the B-30 industrial territory to circular economy by articulating a shared agenda with the goal of zero waste generation.

- To change mindsets and increase the interaction between quadruple helix players. Research and innovation are linked to complex ecosystems that involve the different players in the quadruple helix (government, academia, companies and civil society), as well as flows of people, ideas and financing that generate multiple interactions. Accordingly, the traditional concept of R&I as a linear process has been replaced by the idea of dynamic interaction with many different input points and feedback loops and a multidirectional information flow.

Thematic Focus: **Zero waste and circular economy**.

Nordland (SeeRRI partner)
Challenges: In Nordland the coastline and sea play a crucial role in key industries such as seafood, transport, tourism and energy. And the energy sector, including offshore wind and oil extraction, competes for space with the traditional fishing industry. Nordland´s coastal communities faced tough long-term challenges such as depopulation, an ageing society, climate change and environmental pollution. In governance perspective, what is the way to balance competing interests in coastal development? What is the approach to find the right balance between creating incentives for industry and protecting the environment?

Thematic Focus: **Responsible coastal management.**

Haifa (Israel) (SeeRRI NAT)
Challenges: Haifa has the worst air quality of all the cities in Israel, leading to high rates of respiratory diseases and cancers. The municipality has set itself the goal of transferring the heavy polluting industries away from the bay and replacing them with clean air employers. There is clear resistance to this from the established interests, unions and port management. The focus is on encouraging a start-up culture, to retain the young talent in the city, and improving the tourism profile with a new international airport and developing other tourist attractions, moorings commerce and housing. The complex nature of this transformation will benefit from the collaboration of all stakeholders to find win-win strategies. It is hoped that the SeeRRI methodology can contribute.

Thematic Focus: **Air quality.**

Montenegro (SeeRRI NAT)
Challenges: After a 30-years-long unsatisfactory transition from socialist planned economy to a capitalist one, Montenegro needs a new wave of industrial development and entrepreneurship based on global opportunities which will at the same time keep the high value of its environment, so important for the people´s identity and for overall wellbeing. How to make a completely different investment strategy from what has taken place in the last 30 years and co-create solutions which would change the mindset towards being more entrepreneurial and aware of sustainability issues?

Thematic Focus: Entrepreneurship and business investment to create a **turnaround towards smart specialization and the SDGs.**

Ostrobothnia (Finland) (SeeRRI NAT)
Challenges: The region is well known for its energy technology cluster, part of an industrial sector which is also active in environmental issues, perceived as a business opportunity. But green transformation is a huge concept and requires wider change in society as a whole, as shown in the European Green Deal initiative. So, the main challenge is how to integrate green transformation into existing regional activities.

Thematic Focus: **European Green Deal inclusion in smart specialization activities.**

Serbia (SeeRRI NAT)
Challenges: What is the way forward? How to halt emigration of workers that made Serbia loose more than 5% of its population in the last decade? Is there a policy remedy for brain drain and the decreases of the country´s competitiveness, as also happens in other places in Europe? How to make growth inclusive and environmentally sustainable at the same time? And all this while rising inequality, precarity and lack of social mobility are undermining social cohesion with a growing sense of unfairness, perceived loss of identity and dignity, weakening social fabric, eroding trust in institutions, disenchantment with political processes and an erosion of the social contract.

Thematic Focus: **Work force** needed for economic growth and the implementation of smart specialization.

The formulation of challenges is substantially different from one territory to another but in all cases responsibility, in the strong sense of the term, is clearly present and in a way directly connected to the overall challenge of sustainability.

3.4. ANTICIPATION AND TRIGGER PROCESSES

A way of inquiring into the interdependency between the R&I processes we promote in the present and their future consequences is through Proactive Anticipation, i.e. through the deliberate elaboration of Future Scenarios. This is a practical exercise to raise the awareness of stakeholders at territorial level about their collective capacity to co-create their own future (but also to anticipate less desirable ones). Such an exercise is developed in a systematic way by WP3 (Stakeholder Engagement), first through the identification of a wide set of Influencing Factors (see SeeRRI Report D3.1). A STEEPLE approach is used, meaning that relevant factors are scanned across Socio-cultural, Technological, Economic, Ecological, Political, Legal and Ethical dimensions, producing a first list of up to 105 factors. At the moment of writing the present report, the process of identifying Future Scenarios has only been developed with the stakeholders of the B-30 case. It will also be done with Lower Austria and Nordland in the coming months. In all cases, a systematic screening of factors is done in several stages to reduce the whole set to one retaining only the most influential factors in a specific territorial context.

The Thematic Focus of B-30 is "Zero waste", i.e. a vision of radically circular economy. The final selection of Influencing Factors for this case was the following:
- Education and training
- Resistance to change
- Industry in the territory
- Governmental support
- Research and innovation
- Absorbing knowledge and technology
- New technologies
- Business models
- Skilled employees
- Shared agendas

Based on this set, four different Future Scenarios were developed by the participants in a workshop with stakeholders (on 14/2/20 in Barcelona). The scenarios will be documented in detail in SeeRRI Report D3.2, Briefly, they can be summarized as follows:

- Scenario A brings in a more conscious, empowered and inclusive society, with a transversal governance oriented towards territorial challenges and social needs, based on shared agendas and transparent processes.

- Scenario B foresees a technology-enabled bottom-up democracy promoting flexible "degrowth" (a policy promoting the abandonment of GDP growth as main goal of the economy), with connectivity as the foundation for collective intelligence to tackle societal needs.

- Scenario C is "Big Brother 2084", with society under technological control by big corporations, education and research privatized and high levels of inequality, while "Zero waste" is achieved through exhaustive control.

- Scenario D envisions a new creative techno-hippy society, in which education and all resources are focused on promoting creativity in a continuously changing environment, populated by city clusters.

We note the ambivalence present in the development of these Future Scenarios regarding the role of technology and in particular of digitalization. While there is a clear desire for the use of connectivity and digital tools as a means to empower citizens and enable their creativity, they could also be instruments for a more effective control of society by big corporations. The relationship between digitalization and sustainability did not appear clearly in the discussion, or at least not as much as the political dimension of technology-intensive futures. It seems that significant efforts are still needed to question and imagine how further technological development could help in achieving the overall goal of sustainable wellbeing.

It could be argued that thinking about the future does not necessarily make us think differently than in the present. Moreover, it can be shown that many anticipatory exercises are no more than structured extrapolations of current trends and conceptual frameworks as if these were going to persist in the future. This is an obstacle to the opening of our mental space to the true novelties that could emerge. It is also related to the mechanistic worldview questioned in 4.2.1. Hence, much still needs to be developed for a proper exploitation of the tool of Future Scenarios. To that end, complexity-oriented perspectives are not only welcome but required, because they leave room for the unexpected [Poli 2017]. A step in this direction is to use a framing like the one depicted in figure 17 [EEA 2019, Geels 2006], which is consistent with our perspective on emergent properties in complex systems (see 4.5.3 and 4.6.6). Here, social transitions and transformations are not conceived as linear extrapolations but as the outcomes of dynamic processes in which different trends and forces enter into conflict, first to weaken and destroy existing configurations of social processes, then to create new configurations based on emerging innovations. Though, there is no guarantee that those new configurations appear, nor that they unfold smoothly or are necessarily positive in all aspects. The Scenario C "Big Brother 2084" is an example of a viable reconfiguration, which would be judged as negative by many.

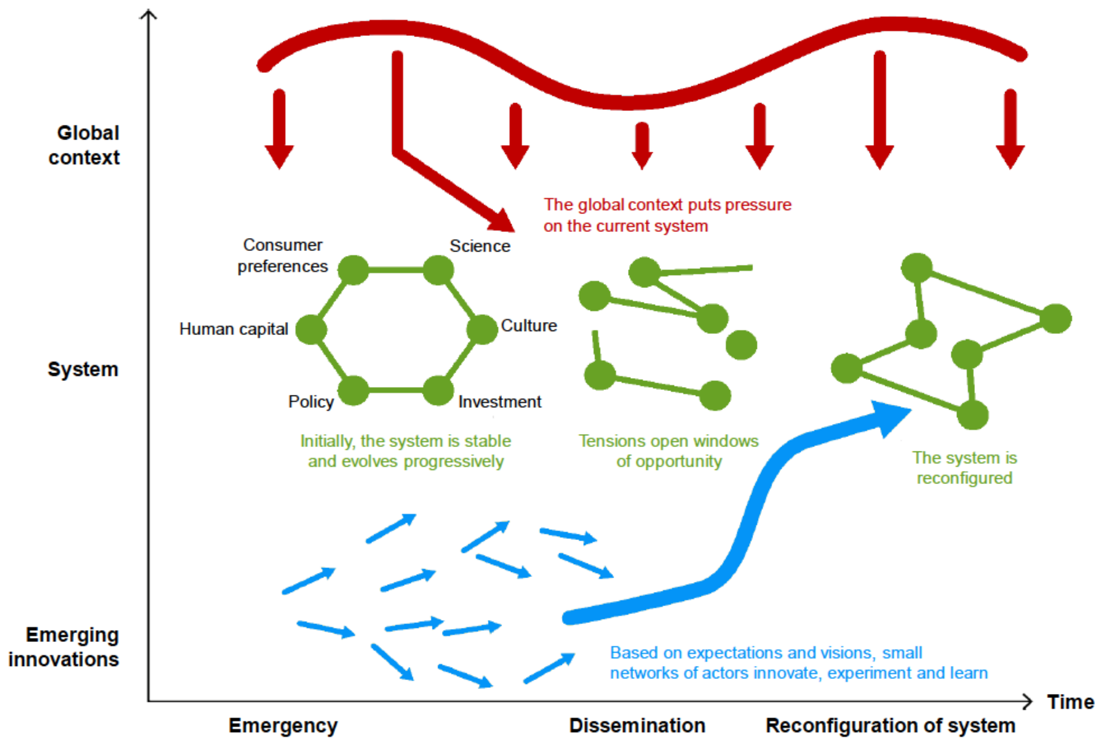

Figure 17. Multilevel perspective on social transitions (source: EEA)

In SeeRRI, the exercise of contextualization with Future Scenarios is useful, especially in refining the formulation of territorial challenges. Thinking about the future is also a strong invitation to identify and describe both the desires we have and the visible difficulties to make them real. But are our desires strong enough to initiate the processes triggering the transformations we need? From the perspective of complexity and emergence, as described in 4.6.6, this cannot be guaranteed. SeeRRI posits that RRI can enable transformations of territorial R&I ecosystems towards self-sustaining states in which societal challenges are effectively addressed. The main trigger process for those transformations to happen is beyond the scope of SeeRRI or the capacities of its partners and stakeholders: it is the evolution of humanity at large which is bringing us to the conjunction of many critical challenges at the same time. The pre-condition of being in the vicinity of a critical point is already met, although not universally perceived, and not uniformly expressed in all contexts and places. Then, within the scope of SeeRRI the most important trigger process is to create the space through which territorial communities can deliberately intend to orient the coming bifurcation into a desirable direction. To this general end, a number of sub-processes are already in place:

- The engagement of and conversations with territorial stakeholders,

- The onset of the Mutual Learning Process (see 2.3 and 3.1) and elaboration of the initial Set of Questions (see 3.2) and,

- The creation of Shared Agendas and formulation of challenges (see 3.3).

None of these trigger processes is final. They all lead to further explorations, among other means by identifying concrete actions to be implemented, both at the level of individual institutions and in the context of the territorial R&I ecosystems (this is being done in T4.3 and WP5). As said, no guarantee of success in the transformations envisioned can be delivered at this stage. Though, everything has been put in place to ensure that the steps taken are consistent with the complexity of the challenges.

3.5. BEYOND SEERRI

"Beyond SeeRRI" means different things. For one, it is about the continuation of the processes initiated by SeeRRI in the three territories involved in the project, beyond the date of its termination. Once engaged the stakeholders and created the space for Mutual Learning, there are good chances that those processes will continue because autonomous dynamics are being ignited and they will continue to be fueled by the relevance of the territorial challenges formulated under the general umbrella "Wellbeing(s) in Biosphere": "Decarbonization" in Niederösterreich, "Sustainable management of coastal resources" in Nordland, "Zero waste" in B-30 (Catalunya). The elements making these challenges relevant will not disappear, rather the contrary. Moreover, the consequences of the Covid-19 pandemic, though still unclear, may become a reinforcing argument for the vision of "Wellbeing(s) in Biosphere". In any case, for the long-term sustainability of the consequences of SeeRRI in the territories, the elaboration of contextual and lasting answers to Questions #4 to #8 of the Set of Questions (see 3.2) is critical: the success of RRI-enabled R&I ecosystems depends on them. As far as the territorial stakeholders are concerned, those questions will be addressed during the rest of the project. But this reflection also includes a number of aspects beyond what is in the hands of SeeRRI partners and territorial stakeholders: these will be addressed in Policy Recommendations at a later stage of the project.

"Beyond SeeRRI" is also about the applicability of the contents developed in this Report to other contexts in which the same type of purpose is pursued. From this point of view the applicability is indeed very high. The Thesaurus (Section 4) is of universal validity, it contains concepts, knowledge and approaches which can be used in a wide variety of contexts: evolution in the areas of knowledge described is expected, but changes in the epistemological framing of human activities are slow enough to ensure that a shift towards a complexity perspective will mean a significant innovation for years and decades to come. As such, the Thesaurus has the potential for a long period of exploitation.

In turn, SeeRRI Conceptual Framework (Sections 2 and 3) is not a blueprint whose design would have to be dramatically changed in another territorial context where the same intention of SeeRRI would exist. Of course its application depends very much on the details of the three territories involved in the project. But neither the 6+1 fundamental assumptions of the Framework, nor the Set of Questions, nor the spirit inspiring its elaboration are limited to a few particular cases. As a consequence of the complexity approach on which it is based, the SeeRRI Conceptual Framework is by construction resilient: it can absorb well the perturbations derived from its use in contexts different from those for which it was originally conceived.

4. THESAURUS OF CONCEPTS

This is an abridged version of what is developed at length in the Annex to D4.1. The focus here is on a brief explanation of each concept (or area of concepts) and why it is relevant in the context of SeeRRI.

4.1. THE WAY WE THINK

4.1.1. Frameworks

We propose to use the following definition:

> *a **conceptual framework** is a set of organized assumptions which frames the analysis on a specific matter and is useful to create knowledge, implement deliberate actions and deliver outcomes in a systematic manner, in particular in the course of a project, or a series of them.*

SeeRRI works at the confluence of two policies of the European Union, namely Responsible Research and Innovation (RRI) and Regional Research and Innovation Strategies for Smart Specialization (RIS3). Both policies have developed their own frameworks and best practices and SeeRRI builds upon them but needs to go beyond because it recognizes that:

- Regional R&I ecosystems of actors are complex systems, they do not fit into linear, mechanistic descriptions of how social processes take place,

- The conjunction of RRI and RIS3 is itself a process of learning and transformation which cannot be effectively planned in a purely linear way.

Consequently, the SeeRRI Conceptual Framework is conceived as a "question machine" based on a state-of-the-art understanding of how complex systems learn and evolve.

4.1.2. Epistemology

Epistemology studies the nature of knowledge and the practices, rules and conditions applying to the process of creation of knowledge. The word is also used to designate each of the different theories of knowledge, not only the discipline as a whole. It is relevant in the context of SeeRRI because responsibility in research and innovation requires making explicit some questions directly related to epistemology. Is the responsibility of knowledge itself a matter of concern? Does the nature of knowledge make it "objective", beyond the reach of human passions and miseries, and then the issue of responsibility affects only the use of knowledge? What makes that knowledge creation can be considered as responsible? [Kunneman 2010]. RRI is itself an epistemological endeavour, a reflection on the nature of knowledge and the quality of the process by which knowledge is created.

While SeeRRI is not going to develop its own epistemology, it needs to build upon perspectives of knowledge consistent with the idea that entities and processes of R&I form ecosystems, at different geographic scales. A good point to start elaborating on that need is to address the issue of how knowledge is related to perception.

4.1.3. Perception and Cognition

Our conscious mind does not have a direct access to reality. The access is mediated by our perceptions through multiple channels of communication, most of them unconscious. Our mind makes sense of the flow of perceptions through frameworks of interpretation. These play a fundamental role in the construction of our conscious understanding of reality (what we usually call "knowledge", see figure 18).

Figure 18. Mediations between reality and understanding (source: own elaboration)

At the same time, our mind is not blind to this, so we are able to consciously question how we think about a specific subject. This reflexivity starts by identifying the contours of the frameworks of interpretation we are using, and making explicit what is usually implicit. This is what SeeRRI Conceptual Framework does: elaborate and make explicit its main underlying assumptions. These are statements translating our understanding of the domain in which we work and the ambition of what we pursue. And the relationship between the conscious adoption of a purpose and the framework required for that purpose to be fulfilled has also to be questioned.

4.1.4. Conscious Purpose

According to a frequent way of reasoning, if we want to achieve an explicit goal (e.g. deploying RRI practices across R&I ecosystems), the first step consists in consciously defining that goal in a precise way, then identifying a path of purposeful steps towards the goal and completing our arrangement with a set of indicators meant to measure the degree of achievement of the goal. By doing this we are adopting, consciously or not, a certain framework to formulate what we intend to do in a "problem-solution" mode with a linear perspective: we know where we are and we define where we want to go, it is just a matter of taking the steps forward. It may look natural, but it is based on a certain epistemology, that of "conscious purpose". This implies first that we put ourselves as external observers of the system which we want to change. And second that we have the capacity to perform a number of operations on that system which will make it to change in the desired direction. This is correct in many ordinary actions but may be problematic when we intend to change a complex system, as does RRI.

A case in point is the "War on Cancer", as it was framed at the times of the US Nixon Administration in 1971. The obstacles preventing discovery of a cure for cancer come from its inherent biological complexity [Jupp 2018]. Many of the advancements related to cancer actually came from the investigation of the genome, an example of curiosity-driven research oriented to increase our knowledge of life at large rather than a purpose-driven endeavour oriented to cure specific diseases. Not least, framing a human initiative in war-like metaphors leads to specific actions: declaring an enemy and defeating it, generally by destructive means. This metaphor is again being used with Covid-19. But maybe by choosing the wrong framework we pursue our goal in the wrong way. All cancer drug therapies have in common that they seek to kill cancer cells and they essentially fail to cure cancer [Huang 2014]. We reason within our consciousness, so we cannot escape from it. But it can make us aware of its own shortcomings. One of them is to ignore the systemic nature of reality whenever we need to achieve an immediate and urgent goal. But when the nature of the goal is itself systemic (as it is in SeeRRI), it seems better to integrate that characteristic in the framework we use. Doing otherwise would make us victims of our blind spots.

4.1.5. Blind Spots

The physiological "blind spot" is the point of entry of the optic nerve on the retina, which by construction is insensitive to light and hence creates an obscuration of the visual field. As a metaphor, we could say that we have blind spots in our observation of the world and of ourselves, which can produce shortcomings in our understanding, especially when they are produced by our unwillingness to see certain aspects of reality. From the point of view of cybernetics (see 4.2.5), human beings as well as societies and ecosystems are self-corrective systems:

> *"They are self-corrective against disturbance, and if the obvious is not of a kind that they can easily assimilate without internal disturbance, their self-corrective mechanisms work to sidetrack it, to hide it, even to the extent of shutting the eyes if necessary, or shutting off various parts of the process of perception."* [Bateson 1968]

Possibly the first blind spot is to think that we do not have blind spots, that our access to reality, even if imperfect and incomplete, is nonetheless objective and continuously improving. This idea could very well prove false. Also, the hypothesis that reality has to be coherent according to what we consciously consider as coherent has been strongly challenged by the developments of physics in the 20th and 21st centuries [Fiorini 2018]. In addition we only give the status of "knowledge" to what we can express through human language while, as Ilya Prigogine said, *"the world is richer than it is possible to express in any single language"*. Our consciousness makes us aware of its shortcomings. The equivalent of the solution to the physiological blind spot is not built into our mental frameworks, it requires attention and the development of a specific kind of thinking, as described in 4.2.

4.2. MODELS OF THOUGHT

4.2.1. Mechanistic Thinking

The paradigm of knowledge of classical mechanics was established at the times of the Scientific Revolution of 17th and 18th centuries and it remained at the core of physicis for around a century. The following are its main assumptions:
- Dualism and objectivity;
- Rationalism;
- Separation of scales and contexts;
- Reductionism (see 4.2.2);
- Linearity;

- Static equilibrium;
- Determinism.

The value of these assumptions has been asserted over time by both the theoretical and practical developments derived from them. Success did not materialize only at the theoretical level, such framework has been the foundation for a myriad of practical applications, many of which already existed before the emergence of mechanics as a science (e.g. large buildings, clocks, mills, printers, artillery, and so on) but greatly benefited and expanded in scope, productivity and quality. At the same time the limits of validity of this coherent paradigm of thinking have been explored as well. Physics has since long entered into a dynamic process of creation of new paradigms of knowledge, every time the incumbent one proved to be unable to explain observed phenomena [Fiorini 2018]. Nowadays the universality of the assumptions listed above is questioned by epistemology, based on the inadequacy of using mechanicism to analyze complex phenomena present everywhere. The mechanistic paradigm is still at the center of our frameworks of interpretation, at least in the Western cultures who have largely shaped the globalized humanity we live in. But this does not mean that it is the appropriate framework to deal with challenges of transformation of the kind that SeeRRI envisions.

4.2.2. Reductionism and Holism

Reductionism is the idea that applying techniques of reduction to the object of our analysis increases our effectiveness in the process of understanding that object. One technique is to build simplified models which become the object of our analysis as if they were the reality they represent (as a map represents a territory). Another is to decompose reality into smaller constituents, assuming that the behaviour of the whole can be deduced from the analysis of the parts, while their connections and interdependencies generally play a secondary role. Reductionist thinking and methods have been foundational of many of the areas of modern science. In as sense it is impossible for humans not to be reductionist: we cannot perceive the aspects of reality to which our channels of perception are not sensitive (although we have worked to overcome this with new artifacts such as the microscope and the telescope) and only part of our perceptions get to our conscious mind (although we are consciously aware of this limitation).

The practical effectiveness of explanations obtained through reductionist methods is considered as an argument good enough to validate the methods, and this is usually an invitation to generalize them. But the limitations of the effectiveness of reductionism appear with clarity whenever complexity manifests itself, especially in the form of emergent properties of a whole which are not deducible from the properties of the parts. Most natural and human systems are actually complex (see 4.5.1), they are made of large assemblies of autonomous parts interacting between each other in non trivial ways, and this is also the case of the territorial R&I ecosystems that SeeRRI addresses. For such systems reductionism needs to be complemented by holism, an approach which focuses on the study of complex systems as wholes. The relevance of holistic thinking is growing inasmuch the consequences of our lack of understanding of complexity are becoming more evident. The awareness is now with us that science and technology, as practiced in the last three centuries, can be at the same time an extraordinary factor of progress for humanity and the origin of many negative consequences, some of them potentially leading to self-destruction at a global scale. As a response to this situation, RRI and its questioning of unintended consequences of R&I take a holistic perspective.

4.2.3. Systems Thinking

A system is a coherent set of interdependent parts. It would not exist without the parts nor without the relationships between the parts giving to it an overall coherence. Systems thinking is the most general kind of answer to the limitations of reductionism. The approach builds upon the consideration that reality is systemic, it is a system populated by systems. From the general definition of a system it is difficult to find anything which is not a system, but mechanicism deals well with systems which are either simple (a ball, a chair,...) or complicated (a car, a plane,...) but not complext. On the contrary, for the analysis of complex systems mechanicism and reductionism are insufficient, or even inappropriate.

Commonalities among systems are important: they have boundaries and internal structures, they depend on their environment and their internal configuration of parts, they exhibit behaviors which can be synergic or emergent (the whole being more than the sum of the parts), and in the case of living beings they can develop intentional actions. Some behaviors are relevant and widespread if one looks at manifestations of life with a systemic lens:
- Persistence;
- Adaptation;
- Homeostasis and resilience;
- Feedback loops;
- Learning and shifting.

4.2.4. Processes and Process Philosophy

Process philosophy considers thatreality is the joint outcome of countless processes taking place in parallel over time in specific places and contexts and producing structures in permanent evolution and interaction. Structures are configurations reflecting the state of play of processes at a certain moment. Processes are permanently exchanging energy, resources and information with their environment, created by other processes. There is nothing purely static in them and their persistence depends on their adaptation to context.
Processes are not manifestations of a larger and coherent whole, they are autonomous and engaged in the pursuit of persistence. This also means that they can be in conflict with each other, although collaboration, concatenation and intertwining of processes are much more often observed in nature than competition [Gorissen 2020]. Also, from the conjunction of processes self-organized patterns can emerge (see 4.5.3). And this perspective is aware of the existence of different scales and levels of processes, organized in some kind of hierarchical manner. Processes can have sub-processes and so on, although relations between different levels may not be as simple as implied in the reductionist perspective (see 4.2.2) and the meaning of "hierarchy" may be ambiguous (see 4.6.3). Complexity thinking is to a large extent built upon process philosophy (see 4.5.1).

4.2.5. Cybernetics

The word "cybernetics" was used in ancient Greece to express the governance of people. In modern times it is a discipline dealing with communication and control, and questioning previous conceptions of causality. Linear sequences between cause and effect, and hence a linear conception from purpose to effect, are not necessarily incorrect but at least incomplete. They ignore potential reactions and feedback loops, which is not appropriate when dealing with living beings, and even less if we cannot take the position of an external observer because we are part of the system under analysis. The design of feedback loops to provide stability to engineered systems (see figure 19) has been part of cybernetics since its inception. But the existence of feedback has wider implications: it outlines the relevance of interactions between parts of a system and the information they carry, and gives a substantial role to communication in conditioning the behavior and stability of systems. By doing that cybernetics opened the door to the conceptualization of complexity (see 4.5.1). And it outlined that all living systems are complex, full of interactions and feedback loops, sometimes extremely intricate. Moreover, it led to the evidence that the relationship with a complex system does not follow the simple cause-effect scheme, it resembles more to an endless cycle of questions and responses.

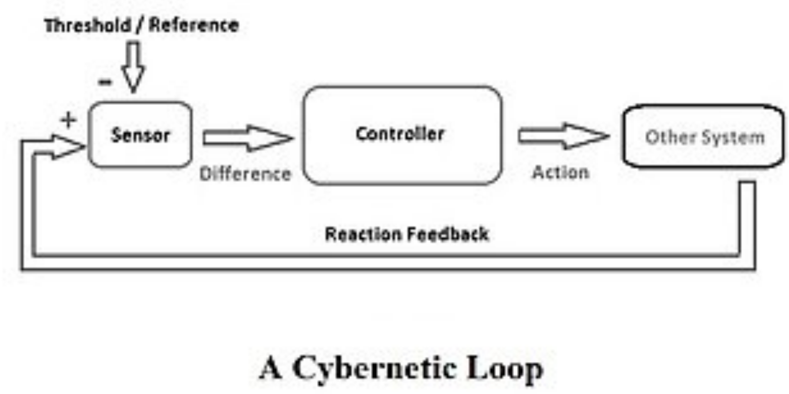

Figure 19. Scheme of a basic feedback loop (source: Wikipedia)

The study of feedback loops acting directly upon a system is now labelled as "first-order cybernetics", while new branches have emerged, as cybernetics of second or higher orders (see 4.6.2).

4.3. INNOVATION AND BEYOND

4.3.1. R&I Processes. Innovation Theory

The current conceptualization of R&I processes derives from the ideas developed after World War II in the USA [Bush 1945] and later replicated by most industrialized countries. It includes a number of ideas still relevant to this day:

- Research and innovation are major expressions of human genius and the foundation for progress of societies, and as such their development should be promoted;

- R&I not only bring better responses to human needs but also protection from a variety of threats and, generate economic growth and prosperity;

- With these arguments in hand, it makes sense for governments to invest massively in R&I;

- The concrete and most effective way to foster R&I is through the existence of different kinds of institutions playing different roles in an arrangement of processes leading from fundamental research to practical applications;

- A requirement for such specialized institutions to be effective is to selectively enroll the most capable people and ensure excellence through competition, collaboration and emulation among the community of scientists and innovators.

The arrangement of R&I processes can be represented as in figure 20. Upstream, funding comes mainly from governments, especially due to the strategic role of technology in geopolitical and security terms, but private sources of funding, high-tech industries and the communities of scientists and innovators also play their role in shaping the decisions of R&I agendas. Downstream, the ultimate test of technological innovation is left to the markets. Actually, the pathways from applied research to applications and from these to commercial exploitation are poorly represented by straight lines. Many unexpected things can happen in the intermediate processes and conversely many expected things may not take place. Nevertheless, there is linearity in the deliberate purposes: innovators, start-ups and corporations intend to bring their innovations to commercial exploitation, as the realization that their ideas were appropriate, timely and well implemented. This validation based on market results has evolved in recent decades along with the general trend of financialization of all economic activities.

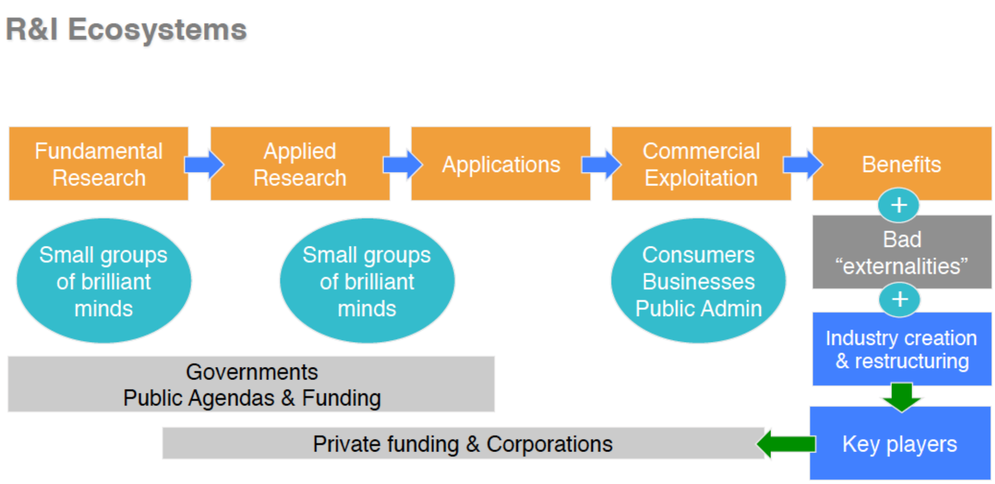

Figure 20. Conceptualization of Research & Innovation processes (source: own elaboration)

The expression "R&I ecosystems" outlines the dynamic relationships between the organizations and individuals involved in R&I and how they impact on society. Real processes do not happen in linear ways and complex patterns of interactions are established among a broad set of actors at local, national and international levels. Though, this complexity does not break with the distribution of roles in figure 20. Such arrangement has been extremely successful in its expansion and impact in the last 70 years. R&I, as they exist today, are not the outcome of the execution of a well designed plan but the overall success was actually expected to happen out of the systematization and exploitation of scientific inquiry and technological development. Though, that effectiveness produces unexpected and not always positive consequences. These include the possibility of mutually assured anihilation through a vast arsenal of weapons of mass destruction, as well as real threats of self-inflicted collapse, catastrophes and perhaps human extinction, due to our indiscriminate use of certain technologies to promote material development, such as fossil fuels. Climate warming or the widespread pollution by plastics are just two examples of undesirable effects of R&I, of such size that it is quite strange to label them as "collateral". A shift in our comprehension could come from considering the negative outcomes, as well as the positive, as emergent properties of our complex R&I ecosystems.

Alignment between the extraordinary momentum of technological innovation (especially in areas such as digitalization and AI) and societal challenges (as compiled in the Agenda 2030 [UN 2015]) is not happening spontaneously. That momentum has its own dynamic and autonomy, largely independent from the pressing issues we face [Alvarez-Pereira 2019]. This imbalance justifies deploying RRI policy as a strategic lever to reframe R&I ecosystems away from the possibility of collapse. In order to increase chances of success in this endeavour, SeeRRI proposes to adopt complexity theory to understand better not only the evolution of the R&I ecosystems as they are but especially what kind of additional layers of contextualization and interactions are needed to ensure that the framing of Responsible Research & Innovation (RRI) pervades the whole sphere of R&I.

4.3.2. Paradox of Agency. Theories of Change

The concept of agency refers to the capacity of humans to understand reality, make choices and act consciously and purposefully to change aspects of their environment (social or natural). The institutionalization of R&I activities (see 4.3.1) uses this concept in an extreme way: they happen in a small elite of global institutions attracting the most brilliant minds who are clever enough to understand how the world works and change it in a desirable direction. This locates R&I outside of society, bringing the message that "innovation is unstoppable" and that society has to adapt to it, as if it was a natural phenomenon on which we have no influence. This, for the immense majority of people, is actually a denial of their own agency. It is the denial as well of the social nature of R&I processes. Furthermore, we do not consider that the exercise of human agency at the highest level of excellence in scientific knowledge, technological acumen and management techniques can possibly produce negative results as a direct outcome. We label them as "collateral" or "negative externalities", but they happen at scale, as a consequence of our blind spots on the nature of conscious purpose (see 4.1.4 and 4.1.5).

Taking into account the above, how to create the changes in the world that we need to succeed in a holistic transition towards sustainability? We refer here to the four scenarios presented in table 2:

- The "fatalist" scenario is the one in which we live. Human systems are so stuck in their own logic of operation that we are not able to create the required transformations at the appropriate pace (e.g. climate warming or Covid-19);

- The "individualist" scenario ("sustainability through the market") is based on a combination of appropriate regulations and market-driven innovation to do the job. But sustainability concerns are not new [Meadows et al 1972, WCED 1987]. Either we are not using the market tool for sustainability or it does not work well enough, or a combination of both;

Fatalist	Hierarchist
'First, disaster must happen'	***'Let's put a man on the moon!'***
-No governance; wait for events creating windows of opportunity -Actors in stalemate over means and ends	-Top-down central management -Government has power or legitimacy; means and ends clear
Individualist	**Egalitarian**
'Sustainability through the Market'	***'A good transition arena will do it'***
-Price and tax policy -Legitimacy for such policy; ends known; market can solve all remaining bottlenecks	-Multi-actor Arena process; learning-by-doing action research -Means and ends to be clarified; no dominant actor; actors tend to agree on rough direction of change

Table 2. Modes of transition management [Tukker & Butter 2007]

- The "hierarchist" scenario (with a top-down central management of the transition) seems simply impossible, at least in most countries, China being the obvious exception;

- The "egalitarian" scenario (with multi-actor and learning-by-doing processes) is the one with greater chances of sucess. However it requires an epistemological shift to understand how complex systems can change. This is the scenario that policies like RRI are promoting, especially when combined with the capacities of communities of actors at territorial levels, as in SeeRRI.

4.3.3. Communities

Communities are important in the context of creating self-sustaining R&I ecosystems based on RRI. Being part of a community is an all-engaging experience with the complexity of life: communities are not organized into ministries and departments as governments and corporations are, they deal with reality as a whole. Think of a family as the smallest example: members have different roles and perspectives but the family is a whole with no purpose other than living together and ensuring the wellbeing of its members. When thinking about what shapes the beliefs and behaviours of individuals, as well as their relationships with their environment, communities are fundamental. Culture plays a central role, in the sense that what communities share and makes them strong is of a cultural nature: they provide meaning. For most communities a defining and all-engaging element is the territory in which they live: geography, language, history, traditions, local knowledge are not separate departments of a territorial community, they are all intertwined in certain ways of living, working, eating, moving, dreaming, loving in a place. Since they are not purpose-driven organizations, it is quite natural for communities to take care, to provide for one another, especially in times when they are stressed for whatever reason. Wellbeing of members is the closest to purpose that a community could have, and it depends on taking care of each other and of the environment from which resources are obtained. The capacity of communities to organize themselves and take care of scarce resources is a frequent characteristic: commons can be properly and efficiently managed without the intervention of centralized institutions or market actors [Ostrom 1990].

This is relevant when addressing how responsible innovation could work in territorial contexts, at the intersection of RRI and RIS3 policies. Most of communities are located far away from the centers of the globalized R&I ecosystem, and their only option nowadays is to adopt whatever technologies and innovations have been created elsewhere, far from their particular and place-dependent challenges. Within the appropriate conceptual framework, such as the one developed by SeeRRI, territorial communities are able to address, in their own autonomous ways, the challenges of sustainable wellbeing as expressed in their geographical, cultural and historical contexts.

4.3.4. RRI Process Dimensions

We sketch here how the four process dimensions associated to RRI (Reflexivity, Inclusion, Responsiveness and Anticipation [Stilgoe 2013]) are connected to a number of issues outlined in other sections of this report.

Reflexivity is directly related to the frameworks of interpretation conditioning the way we think and translate perceptions into conscious reasoning (see 4.1.2 and 4.1.3). It is a pre-requisite to identify and avoid our blind spots and the pitfalls of conscious purpose (see 4.1.4 and 4.1.5), as well as the foundation of second-order cybernetics (see 4.6.2) and epistemological advances (see 4.2).

Inclusion is related to the role of communities (see 4.3.3) and interdependencies (see 4.5.2) and the need to have a multiplicity of descriptions (see 4.6.1). It gives its full meaning to human agency in the context of R&I, now limited to the small elite of institutions developing R&I activities (see 4.3.2). Also, it opens the door to consider mutual learning as the most effective way for transformation (see 2.3).

Responsiveness is related to the absence or insufficiency in R&I agendas of elements expressing the aspirations of humanity (see 4.4.4 and 4.4.5). It considers many facets for positive transformations (see 4.3.5). And it addresses the limitations of conscious purpose (see 4.1.4) and other approaches to the question of how complex systems can change in a desired direction (see 4.5 and 2.3).

Anticipation is related to the systemic nature of reality (see 4.2.3 and 4.2.5). Anticipation cannot just be an extrapolation of the present, it has to build upon the best of our understanding of complex systems (see 4.5) and capacities for collective deliberation (see 4.6.1) and mutual learning (see 2.3).

4.3.5. Transformations

In the SeeRRI approach R&I are expected to have a transformative role, in the sense of the term "transformation" associated with the UN Agenda 2030 of Sustainable Development Goals (SDGs) [UN 2015]. The SDGs mean no less than a complete overhaul of human civilizations. But reality admits multiple descriptions, and the reflection on our systemic dysfunctions and how to solve them also admits multiple approaches. The challenge may be daunting if we recognize that everything is interdependent on everything else (see 4.2.2, 4.2.3 and 4.5.2). This is why, as manifestations of present challenges become more evident, simplistic answers to complex crises are proliferating. This is not the path of SeeRRI, the project dares to face complexity because dismissing it is, to the best of our knowledge, a wrong approach.

Transformations have necessarily multiple contexts (technology, economy, governance, culture, society, and so on). The depth of the challenges and hence of the responses to them is such that there is no straight pathway from A to B in ten easy steps. Transformations will be shaped by a complex ecology of ideas and initatives that are interconnected and not mutually exclusive. The SeeRRI Conceptual Framework does not directly address all the mentioned contexts, but it integrates them through four contexts associated to the RRI process dimensions (see 2.2.5).

4.4. NATURE AND US

The title of this Section wrongly suggests that humans are not part of nature. But this idea of separation is a common blind spot in our relationship with nature, as something different from human-made environment, and also in the dichotomy between nature and culture. From the modern perspective of ecology we realize how much interdependent we are with nature.

4.4.1. Biosphere, Ecology and beyond

In the context of geochemistry four separate components are considered: the geosphere (as the set of all solid parts of the Earth), the hydrosphere (liquid parts), the atmosphere (gaseous parts) and the biosphere as the sum of all living organisms. The term "ecosphere" encompasses biological and physical components of the planet, including the four components mentioned above. The term "ecology" means "the study of our house" and it deals with the interactions among living organisms and their biophysical environment. **In the conception of ecology the idea of evolution is a dramatic change of epistemology**. Leaving behind the consideration of the natural world as static and unchanging, ecology became an effort to understand the dynamic and reciprocal relations between organisms, their adaptations and the environment.

In early 20th century Vladimir Vernadsky widened the concept of biosphere, as ***the global ecological system integrating all living beings and their relationships, including their interaction with the elements of the geosphere, hydrosphere and atmosphere****.* And he defined ***ecology as the science of the biosphere***, necessarily an interdisciplinary endeavour. Vernadsky and others opened the door to an evolutionary perspective of the biosphere as a whole, i.e. as a self-regulating system closed except for the inflows of energy from solar and cosmic radiation and heat sources from the interior of the Earth. The history of the biosphere starts 3,5 billion years ago with processes of "biopoeis" (life created naturally from non-living matter) and "biogenesis" (life created from living matter). Vernadsky also proposed during the 1920s that living organisms could reshape the Earth as surely as any physical force, an anticipatory vision of the modern concept of the Anthropocene [Steffen et al 2007] as a new geological era shaped by humans.

Vernadsky and theologian Pierre Teilhard de Chardin popularized the concept of "noosphere". After the geosphere (inanimate matter) and the biosphere (biological life), the Earth is now in its third stage of development. As the emergence of life fundamentally transformed the geosphere, the emergence of human cognition is fundamentally transforming the biosphere. This systemic perspective integrates the theory of natural selection, which looks at each individual species, in a wider picture. But the evolution of the noosphere is nowadays threatening its own development.

4.4.2. Ecosystems

The term "ecosystem" designates an assembly of living organisms in conjunction with the non-living components of their environment, interacting as a system and linked together through nutrient cycles and energy flows. The concept is also used in non-biological contexts when systems share some of the following characteristics:
- They are dynamic entities, perpetuously changing and evolving. They are influenced by internal and external factors, and subject to disturbances;
- Their vitality depends on flows of energy and materials (in-, out- and internal flows);
- They are dependent on multiple contextual characterisctics;
- They are self-corrective against disturbance through the emergence of feedback loops;
- They are resilient, having the ability to recover from major disturbances.

These features are taken into account in SeeRRI when considering the conditions for R&I ecosystems to sustain by themselves. Without both self-correction and resilience, ecosystems would be unstable and collapse sooner or later. And a manifest characteristic is that diversity contributes to resilience: highly uniform natural or human ecosystems are fragile. Also, causality chains can be complex and take a long time to act. Climate warming is a case in point. Not only feedback loops abound, the chains of events leading from one factor to its ultimate consequences can cover large circles [Bateson 2016]. This represents an epistemological shift: our conceptual framework has to integrate the possibility of long chains of interdependencies producing unexpected consequences of our actions.

On the other hand, collapses of ecosystems are not new in the history of evolution but what is new is the intensity of the impacts of human action on all ecosystems across the planet, of which climate warming and the emergencies it induces are the most spectacular. Hence the study of natural and human ecosystems can no longer be free from the analysis of the human footprints on Earth.

4.4.3. Ecological Footprint

A number of intiatives are raising the awareness on the profound modifications of natural ecosystems due to human activities. The UN Intergovernmental Panel on Climate Change (IPCC) and Science-Policy Platform on Biodiversity and Ecosystems Services (IPBES) are most relevant, among others. These initiatives are systemic within the boundaries of their topic but do not inquire into the interdependencies between their topic and other dimensions of human activity. In particular, ecological perspectives have been disconnected from social and economic perspectives, which main explain why the insufficient political will behind many ecological measures. A more comprehensive assessment of the metabolism of our relationship with the biosphere of which we are part is needed. In the early 1990s Mathis Wackernagel and William Rees defined the concept of **Ecological Footprint** (EF) as a metric measuring how much area of biologically productive land and water an individual, population or activity requires to produce all the resources it consumes and to absorb the waste it generates, using prevailing technology and resource management practices. The EF can be measured in global hectares per person, or in "Number of Earths" required to sustain a specific footprint. Less than 1,7 global hectares per person or, by construction, 1 Earth per person, makes the resource demand globally replicable within the limits of our planet [Wackergnagel & Rees 1996]. **Biocapacity** (also measured in global hectares per person) represents the ability of a particular area to produce biological materials used by humans and to absorb human-produced waste, under current management schemes and extraction technologies. It measures the capacity of ecosystems to regenerate what people demand from them. These indicators of EF and biocapacity do not provide a completely comprehensive representation of the challenges that human societies face, since many relevant aspects are not taken into account. But they are useful in providing an overall outlook and a compelling graphic representation on these issues of critical importance for the future of humanity. As shown in figure 21, at a global level we entered in the 1970s in an increasingly unsustainable regime in which the global Ecological Footprint is higher than the Earth´s biocapacity. In other words we are consuming natural resources at a rate higher than the planet is able to produce them (nowadays it is 70% higher), which leads to the destruction of the reserves of natural ecosystems, a very dangerous path downward. This calls for a dramatic reduction in global EF, as discussed in 4.4.5.

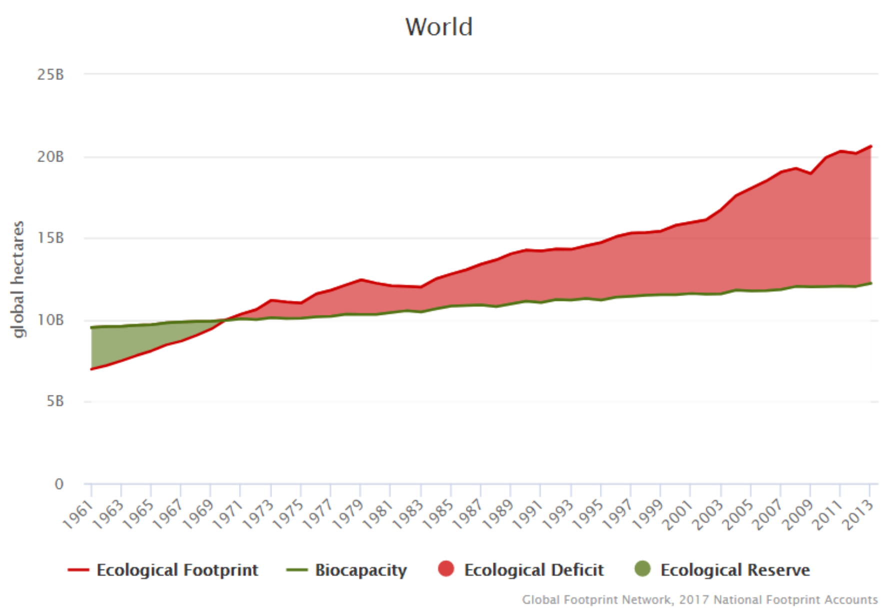

Figure 21. Worldwide evolution of biocapacity and footprint, 1961-2013 (source: GFN)

These metrics can be used to contextualize the situation of the three territories involved in SeeRRI. Data are not available at territorial level, but the national indicators give useful hints:

- In Austria and Spain, the EF has grown substantially in the last 50 years: from 3,5 to 6 gha/px in Austria and from 2,5 to 6 then down to 4 gha/px in Spain. In the aftermath of the crisis of 2008, Spain reduced its EF by one third in less than 10 years;

- Norway has experienced a decline in its EF from a peak of 11gha/px in the early 1970s down to 5,6 gha/px in 2016. This level is still very high but this shows that substantially reducing the EF is not impossible and does not necessarily entail a collapse in human wellbeing.

- Due to different territorial conditions and population densities, the three countries have very different biocapacities per person: Spain has 1,4 gha/px, Austria 2,9 gha/px and Norway 7,3 gha/px;

- Their national deficit or excess (biocapacity - footprint) is totally different: Norway has a positive balance of 1,7 gha/px, Austria and Spain have negative positions (-3,1 and -2,6 gha/px);

- Differences in evolution over time are significant. In Austria, biocapacity has been initially stable and then slightly declining since the 1990s, while its footprint grew rapidly until 2005 and then stabilized;

- In Norway, biocapacity has been significantly declining, especially since 2005, and its footprint increased from the 60s to the 70s and has been declining most of the time since then;

- In Spain, biocapacity has been stable since the 1960s, while its footprint grew rapidly until around 2008 and then collapsed; it has stabilized and now shows signs of growth once more.

4.4.4. Human Development and its Measurement

Historically the concept of development has been associated to the rapid process of industrialization and urbanization that has characterized the evolution of certain countries in the last two centuries and has now become the benchmark for most of them. After World War II Gross Domestic Product (GDP) and its ratio per capita became the metrics of reference to measure and compare degrees of development in different countries. In the early 1970s the Club of Rome disrupted the global conversation about development by raising the alarms about the unsustainability of any model based on the absence of limits to economic growth [Meadows et al 1972]. That had a huge impact, leading among others to the United Nations coining the concept of "sustainable development" in 1987 [WCED 1987]. More than 30 years later sustainable development is still an oxymoron (see 4.4.5).

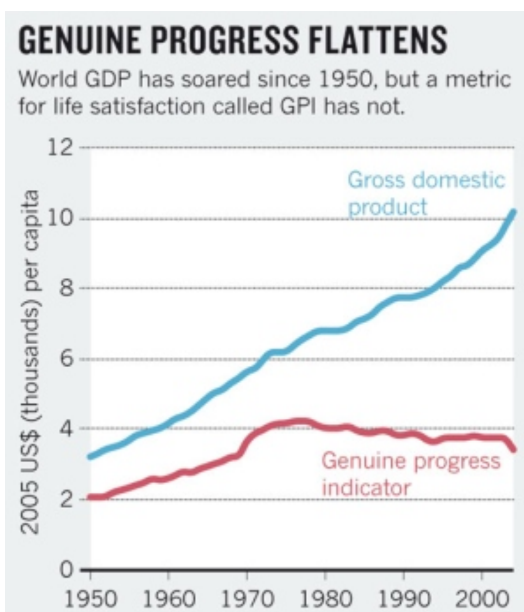

Figure 22. The decoupling of GDP and GPI in the USA (1950-2004) (source: Redefining Progress)

Over time, the conventional framing of development has been questioned in many different ways. In the 1980s ecological economist Herman Daly coined the concept of "uneconomic growth" to designate growth which creates decline in quality of life. Marilyn Waring (from the field of feminist economics) promoted the creation of the Genuine Progress Indicator (GPI) to screen out the negative effects of economic growth. Worryingly enough, GPI is stagnant since the 1970s and has completely decoupled from the growth in GDP, at least in the USA (see figure 22).

In 1990 the UN Development Program started elaborating the **Human Development Index** (HDI) [UNDP 1990], integrating health (life expectancy at birth), education (average years of schooling) and prosperity (average income per capita). A level of HDI higher than 0,7 is considered as "high human development". In 2011 the Organization for Economic Cooperation and Development (OECD) launched its Better Life Index, taking into account 11 dimensions reflecting quantitative as well as qualitative aspects of quality of life (housing, education, happiness, work-life balance and so on).

The same year of 2011 the UN General Assembly passed the resolution "Happiness: towards a holistic approach to development", based on the adoption by Bhutan of Gross National Happiness (GNH) a composite index based on four pillars:
- sustainable and equitable socio-economic development,
- environmental conservation,
- preservation and promotion of culture, and
- good governance.

After long work the United Nations launched in 2015, with the unanimous support of the member states, the Agenda 2030 of Sustainable Development [UN 2015], which includes 17 different dimensions or Sustainable Development Goals (SDGs, see figure 23). This has become the official framework for human development. It informs public and private agendas at all scales and gives a political mandate to align all processes of societal evolution with the SDGs. In the light of RRI promoting R&I processes not aligned with the SDGs cannot be considered as "responsible". But using the SDGs as a compass for policy design and governance is a demanding challenge: the framework is composed of 17 goals and 232 indicators, but they do not represent independent dimensions. Reality cannot be splitted into sealed compartments and considering it otherwise leads to a nightmare of entangled trade-offs. Also, a long list of quantitative indicators will always deliver mixed signals: some will be good, others will be bad, on many we will not know what is going on. While macroeconomic governance is focused on the single goal of keeping GDP growth at the highest non-inflationary level and ignores almost anything else, this challenge of "societal navigation" based on the SDGs is one of the obstacles for translating global debates on sustainability into concrete actions in concrete territories. To continue with the metaphor of navigation, we would need a dynamic sense of wind direction and intensity as well as a tentative course to where we want to go, rather than a large and complicated set of interrelated indicators.

Moreover, as discussed in 4.2.1 and 4.2.2, splitting the monitoring of societal evolution into multiple pieces is the kind of mechanistic exercise at odds with real-world complexity. We rather need to engage in a process of mutual learning (see 3.3). This process starts with open deliberation, done with the partners and stakeholders of the SeeRRI project. At the same time, some kind of overall guidance provided by a synthetic compass is welcome. This is not to say that one indicator is by default less mechanistic than many, but if well chosen the compass could be useful for mutual learning. Monitoring is not useless, but it depends on our expectations: if we believe a set of indicators can truly represent the complex patterns present in society, we are probably misled. However, if we use indicators as alarms leading to uncomfortable questions, that could be useful as a focal point for our inquiry. Our concrete proposal for this synthetic compass is to **consider the state of societal evolution by looking at how much human wellbeing is achieved at what level of ecological footprint**.

Figure 23. The framework of the SDGs [UN 2015]

4.4.5. Wellbeing(s) in Biosphere

In recent years the concept of wellbeing has acquired more prominence in the debates related with the insufficiency or inadequacy of GDP as societal compass. In the context of SeeRRI as a project promoting Responsibility in processes of R&I in territorial contexts, we propose to use the concept of **equitable wellbeing at peace with a healthy biosphere**, in short "wellbeing in biosphere", as the North pole of our compass to navigate the evolution of R&I processes towards Responsibility. We also consider that the pathways towards the realization of that concept cannot be based on universal recipes, they are necessarily dependent on territorial contexts, as developed in the project. This is why the "s" is added in "wellbeing(s)": the same concept can mean different things in different places. To get an overview of the implied challenge we can use a two-dimensional map of Human Development Index (HDI, see 4.4.4) and Ecological Footprint (EF, see 4.4.3). Figure 24 shows the distribution of countries with data of 2016. The size of circles is proportional to each country´s population. The largest circle represents the world with an HDI of 0,7 (i.e. reaching the threshold of high human development), but an unsustainable footprint of 1,69 Earths. Sustainable Development (SD) corresponds to a quadrangle in the lower right side of the graph where HDI is high (> 0,7) and EF is low enough (< 1 Earth). The area of that quadrangle is getting smaller because its vertical dimension (EF) is measured in terms of global hectares per person and the world´s population continues to grow. This graph brings some surprises:

- Sustainable Development (SD) is currently an oxymoron. Countries with high levels of HDI have also high levels of EF: for HDI > 0,9, EF is never lower than 2,8 Earths although it can go up to 5 Earths;

- Many countries with EF < 1 have low levels of HDI. Progress in HDI is accompanied by substantial growth in EF: China rapidly increased its HDI to 0,75, at the expense of having an EF of 2,2 Earths;

- European countries show high levels of HDI at much lower levels of EF than other rich countries (Germany and the USA have simiular levels of HDI with very different EFs, 2,97 Earths vs 4,97). But as of today the EF of European countries is still very high;

- As measured by HDI-EF indicators, best performing countries are Philippines, Jamaica, Ecuador, Cuba and Sri Lanka. These are generally not considered as global references;

- No positive correlation exists between R&I intensity and proximity to Sustainable Development.

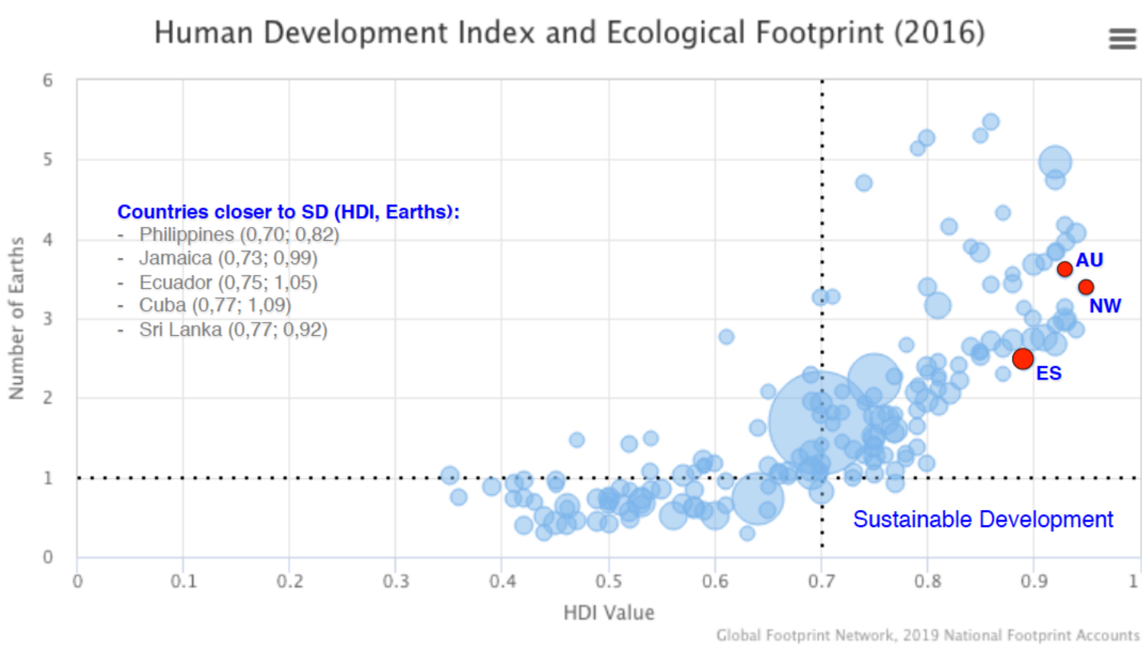

Figure 24. Human Development Index vs Ecological Footprint (source: GFN)

The venture towards SD faces two challenges that we are not able to meet for now:
(1) How can we increase low levels of HDI without increasing at the same time the levels of EF?
(2) How can we decrease high levels of EF without losing established levels of HDI?

Regarding the countries of SeeRRI territories, Austria and Norway have similar positions (HDI > 0,9, EF around 3,5 Earths) while Spain has an HDI close to 0,9 at a level of EF around 2,5 Earths. All of them face the challenge of lowering their footprints while keeping high levels of human development.

4.5. COMPLEXITY THINKING

As H.L. Mencken said, *"for every complex problem there is a solution that is clear, simple and wrong"*. All relevant problems that humanity is facing are complex. They are driven by multiple and interrelated causes, across multiple contexts and interdependencies. Straightforward methods to "solve" complex problems are tempting, but as suggested by Mencken they do not work in real life. What could work, though, is to use an entirely different approach to assess both the problems and our actions.

4.5.1. Complexity and Complex Systems

There are many definitions of compexity, but all of them share the following characteristics:

- Complex systems are **large assemblies of autonomous actors interacting between them and with their environment in non-trivial and especially non-linear ways**. This description is applicable at many different scales, to the assemblies of cells in a body, neurons in a brain, members in a society (human or not), organizations (families, tribes, companies, cities, states, and so on) in a modern human society. It applies as well to ecosystems (see 4.4.2) and to the whole Earth system;

- Not all systems are complex. A car or a plane are examples of very complicated systems, but they are designed not to be complex: we want them to be predictable;

- **All living systems are complex**, whether at individual, group or societal levels. Individuals are themselves large assemblies of lower-scale autonomous actors: they are ecosystems on their own;

- **The overall behavior of complex systems cannot be fully predicted**. The interactions inside and outside a complex system make impossible to precisely compute its trajectory in any modelling space. More generally, radical uncertainy, unexpected behaviors and emergent phenomena are intrinsic manifestations of complexity [Prigogine & Stengers 1997];

- Complex systems are not chaotic, though: they are dynamic, in permanent evolution and open exchange of energy, resources and information with their environment, but their behavior is not erratic;

- **Emergent properties are features of the whole not contained in the parts**. In the vicinity of critical points **creativity** can play a role. Enabled by processes of interactions at high levels of energy exchange, new forms and patterns, self-organization and auto-poeisis may appear (see 4.5.3).

- Analyzing complex sytems is **to look at the interactions and interdependencies within the system and with their environment**. Reductionistism is not sufficient. Complexity is characterized by the widespread presence of feedback loops, possibly long and intricate [Bateson 2016]. They resemble questions and answers leading to more questions, in an endless process of evolution.

These characteristics of complex systems pose significant challenges to our understanding, especially if we have the deliberate purpose to make a system evolve in a certain direction. Complexity thinking is not the ultimate paradigm of knowledge: as far as we can say, such thing does not exist [Meadows 1999]. It is a perspective telling us that we are actually immersed in an endless process of mutual learning in interaction with the systems of which we are part (starting with the billions of bacteria living in our body without which we cannot live). Complexity thinking is a tool at hand, only waiting to be developed in its applications, provided that we recognize the limitations of incumbent epistemologies.

4.5.2. Interdependencies

Interdependency is not the opposite of independence. On the contrary, genuine independence cannot be acquired without an awareness of interdependency. Interdependency is the opposite of exclusion. It states that we cannot ignore how much our life depends on our relationships with a myriad of "others". The central concept of complexity thinking is that in a system we should give priority to the interdependencies between the parts of the system and with what lies beyond the system boundaries.

Interdependency is more than connectedness or interactions. Connections can happen at an infrastructure level (as between nodes of telecommunications networks) but do not even suppose autonomous behaviors of the parts. Interactions do not necessarily imply a permanent state of mutual relationship, as interdependency does. So, complexity is not just about parts connected between each other and occasionally interacting, it reflects a dense web of permanent relationships in which mutual exchanges are the norm.

As far as explanations are concerned our scientific traditions are built upon the practices of separating wholes into parts and reducing dimensionality to a few variables of analysis (see 4.2.1 and 4.2.2). Complexity is a shift in perspective: for all the details it could have, representing a system as a collection of "boxes" and a number of "arrows" between them is insufficient. But if everything is related to everything else we face the nightmare of infinitely-dimensional analysis, and we cannot find a way to take into account all interdependencies in our conscious modelling of reality. Though, the shift from neglecting interdependencies to considering them extends the scope and improves the quality of our questions, and it reveals many of our blind spots. This is why the concept is one of the fundamental assumptions of the SeeRRI Conceptual Framework (see 2.2.5).

4.5.3. Patterns, Self-organization and Autopoeisis

Patterns of forms are abundant and very diverse in nature: symmetries, trees and fractals, spirals, meanders and vortices, waves, bubbles, tesselations, cracks, stripes (figure 25).Their regularity and beauty have been a matter of wonder since the beginning of time. From the perspective of complexity the existence of natural forms is a manifestation of the concept of emergence, by which something qualitatively new appears out of parts which do not contain it. Forms are the outcomes of processes able to create structures, under certain circumstances (see 4.2.4). They require a constant and open exchange of energy, resources and information with their environment, sometimes leading to the crossing of a threshold through which creativity happens (see 4.6.7).

Self-organization is the key feature for the emergence of patterns, as *"a property of complex systems which enables them to develop or change internal structures spontaneously and adaptively in order to cope with, or manipulate, their environment"* [Cilliers 1998]. That feature makes possible that a system adopts a certain pattern which arises from a different state of the system, either disordered or following another pattern. It happens spontaneously but requires certain conditions, in particular that enough energy is available, but not the control by any external agent. The different states of a system can be represented in a map, where certain areas (called "attractors") signal where the system finds a stable balance and can absorb fluctuations without changing its pattern. But if enough energy is fed into the fluctuations the system can shift from one attractor to another, one pattern to another. In the vicinity of such critical situations the smallest fluctuation decides unpredictably whether the system goes one way or another, among a set of patterns in which chaos is also an option. And within that framework the role of far-from-equilibrium "dissipating structures" (see 4.6.4) was identified as the theoretical foundation for emergent patterns [Prigogine & Nicolis 1997].

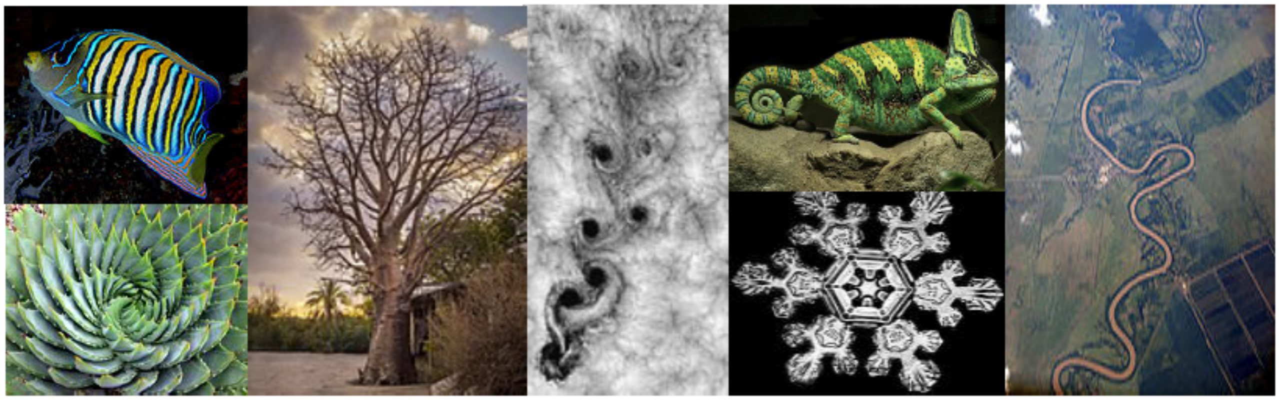

Figure 25. Examples of patterns in nature (source: Wikipedia)

Self-organization is an ubiquitous phenomenon that can be reproduced artificially in simple, non-living systems (e.g. the formation of convection cells in a fluid). It is not the singularity separating non-living things from living beings. But **life, as the complex system par excellence,** has produced a countless number of new and viable forms of living over millions of years.

It is characterized by another feature, "autopoeisis", a synonym of self-creation coined by biologists Humberto Maturana and Francisco Varela. It refers to the unique ability of living systems *"to continuously renew themselves and to regulate this process in such a way that the integrity of their structure is maintained. Whereas a machine is geared to the output of a specific product, a biological cell is primarily concerned with renewing itself"* [Jantsch 1980]. This characterization of living systems opened new avenues for investigation, related to feedback loops and self-referencing (see 4.6.2 and 4.6.3). Autopoiesis implies that the purpose of life is no other than the persistence of life itself and underlines the capacity of living systems to maintain themselves. They do so by developing new patterns: this is the way they can learn and change, adapting to new conditions [Jantsch 1980]. Such fundamental insights provide hints to promote effective strategies in the transformation of R&I ecosystems (see 2.3 and 4.6). Though, in a form of poetic irony, none of the above actually solves the question of why emergence happens, which may continue to be a mystery inaccessible to our understanding [Morin 2017].

4.5.4. Modelling Complexity

The expression "modelling complexity" is an oxymoron. Models are simplifications of reality meant to be useful for our understanding, while complexity thinking starts from the opposite angle, by stressing how risky it is to apply reductionism and simplification (see 4.2.2). But rejecting the idea of modelling complexity leads to think that nothing can be consciously understood about any complex system. Many complexity thinkers work beyond the contradiction between modelling and complexity by assuming that *"all models are wrong, some are useful"*, and recognizining that uncertainty is real, not a collateral effect of the insufficiencies of our techniques which could ultimately be eliminated. Then, a fair modelling starts with making explicit the assumptions taken in the construction of the model(s), as SeeRRI does with the foundations of the Conceptual Framework (see Sections 2 and 3). Also, models of complex systems should be open-ended to expand our capacity for perception and engage into processes of mutual learning. With this in mind modelling complexity might be possible if adopting the appropriate epistemology and techniques [Hoffman 2015].

The richness of the field of complexity has given birth to a multiplicity of techniques of description coming from different disciplines of mathematics and natural sciences [Abraham 2002]. Dynamical systems theory, game theory and agent-based modelling (ABM), complex network theory are among the tools being used to build models of complex systems. As discussed in 4.6, the challenges that complexity poses to our conscious mind may be beyond the reach of modelling and even beyond conventional logic. Conversely, interdependencies can be part of a framework of analysis in any discipline, without necessarily leading to a translation into some kind of mathematical modelling.

4.6. AT THE LEADING EDGE

A number of concepts at the leading edge of systems research are briefly introduced here. They have horizontal implications across several disciplines but do not form a consistent theory. Even for those initiated decades ago, their potential is still largely unexploited. They are elements of inspiration for the SeeRRI Conceptual Framework and especially for the ways it can be used (see Section 3).

4.6.1. Contexts and Transcontextual analysis

Analyzing a complex system in only one context is a limitation that we cannot afford. The Covid-19 pandemic shows it in a tragic way: any of its aspects is linked to many others. Health, science, ecology, cities, transport, industry, economy, politics, technology, education, and still others are relevant contexts, all at the same time. Transcontextual analysis takes for granted that this happens with any complex system: it manifests itself across many different contexts, and its persistence, capacity to adapt and resilience (see 4.5.1) are tributary of that multiplicity of contexts. Since all relevant objects of analysis are linked to different contexts, transcontextual research should be the norm, but solid techniques are still needed to offer multiple descriptions of the way an issue is nested in many contexts, and to get across the boundaries between the different contexts. Not least, transcontextual analysis could potentially offer insights for a system shift when this is required, by identifying where reinforcing mechanisms (see 4.6.6) are loose enough.

To date, the most advanced method of inquiry for transcontextual analysis involves the concept of "Warm Data", defined as *"transcontextual information about the interrelationships that integrate a complex system"*, and the process of "Warm Data Labs", especially designed to engage people into conversations on a complex issue from a transcontextual perspective [Bateson & Schutte 2019]. The format is designed to create the conditions for people to grasp complexity by themselves and initiate dialogues leading to a deeper understanding of interdependencies.

4.6.2. Reflexivity and Higher-order Cybernetics

Cybernetics states that in most of issues direct causality does not have enough explanatory power (see 4.2.5). Complex systems are governed by an interweaving of direct and feedback loops, potentially very intricate. On the other hand our conscious mind is aware of its own limitations and this is the foundation for reflexivity, the capacity to reflect on how we think and act, which is embedded in RRI. Second-order cybernetics emerged to inquire on how knowledge is constructed by human observers with their own frameworks of interpretation. Third-order cybernetics has been proposed to address the subjectivity of the observer (second-order) who observes the feedback loops in complex systems (first-order) [Kenny 2009].

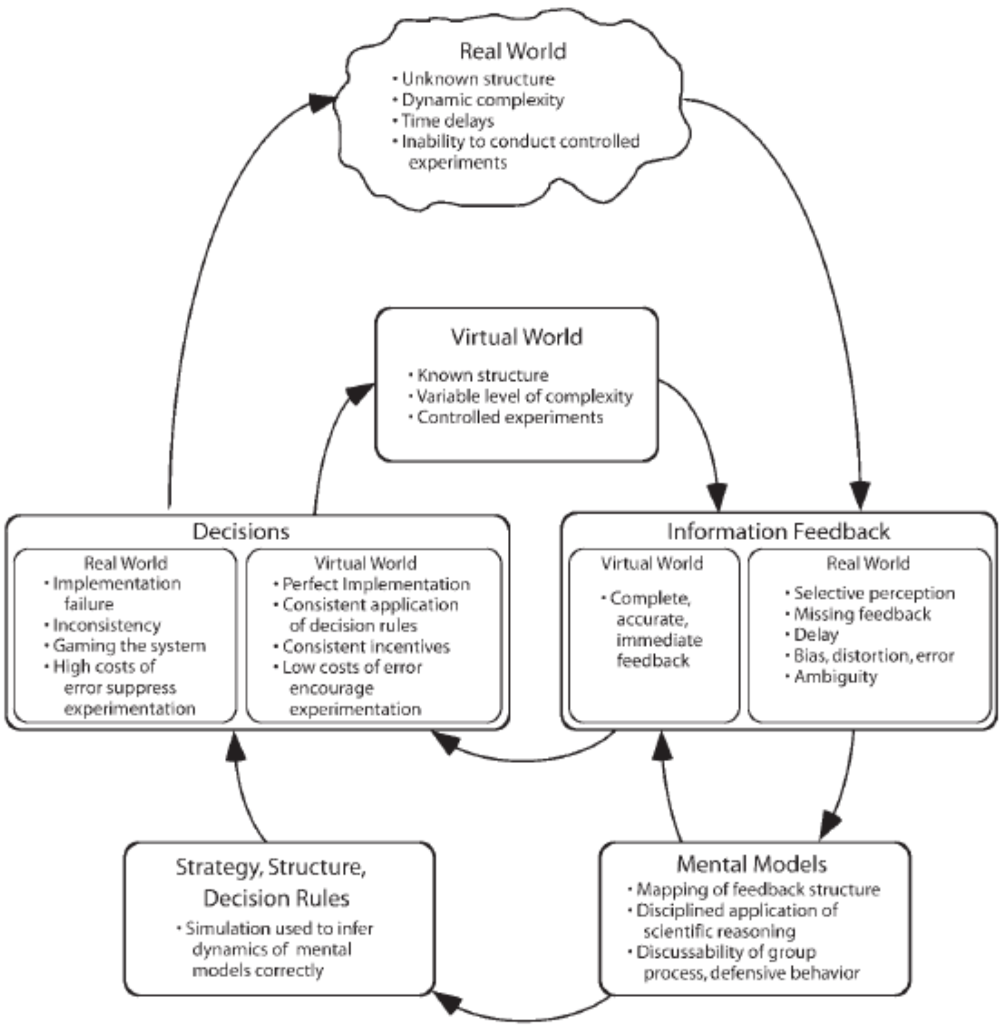

Figure 26. Idealized learning process through multiple feedback loops [Sterman 2006]

A practical application is to ensure that models have epistemological consistency for them to be useful in describing complex systems. From this perspective, models are necessarily open to a wide array of possible futures for the system under anaysis, and modelling is a process of learning nested in multiple feedback loops as depicted by the graph in figure 26. As a consequence, learning about complex systems has to be mutual (see 2.3) [Sterman 2002 & 2006].

4.6.3. Frontiers of Understanding

Architecture of Complex Systems: Holons and Holarchies

"Holarchy" is an attempt to go beyond the concept of hierarchy, building upon many of the characteristics of complex systems. An holarchy is an assembly of "holons", a word used by Arthur Koestler in 1967 to designate something which is at the same time a whole and a part. For instance, seeds are part of a tree, but a seed contains as well a future tree. Seeds and tree form a holon. The same with the genome and the body. So, it is not only that a part at a certain level can be a whole at a lower one. Hierarchies have by definition higher and lower levels but this is no longer valid in holarchies. The bottom can be a top and the top a bottom. A fractal illustrates this absence (or ambiguity) of hierarchy: at each of its levels the fractal is self-similar, it contains the same patterns. So, holons are are at the same time wholes and parts of larger wholes. Individual beings and their societies are holons of intermediate level, in the range of sizes going from the elementary particles to the universe (or the set of multiverses). The concepts of holons and holarchies can be applied not only to biological systems but as well to cultural ones, by considering that the basic units carrying meaning and reproducing themselves as agents of cultural propagation, known as "memes" in the metaphor developed by Richard Dawkins, could be described as holons.

Communication: Double Binds, Schismogenesis

A double bind is the creation of a dilemma when an individual or a group receives contradictory injunctions at different levels of communication [Bateson 1972]. Responding to one injunction creates a failure in responding to the other, so the response is always wrong. In many situations the dilemma is not easy to confront, so the indiviual or the group cannot resolve it nor get out of the situation. If double binds are frequent they can lead to emotional distress and eventually mental diseases or learned helplessness, a situation in which an individual or a group perceives a loss of capacity to be in control of its context and to achieve goals. The expression "double bind" has also been used by Norbert Elias in the context of international relations, to designate situations in which two rival states both portray the other as the agressor and develop highly emotive responses to whatever actions are taken on the other side, leading to dangerous processes of mutual distrust and fear, and potentially of destructive escalation [Elias 1987].

This is connected to another concept developed by Gregory Bateson, "schismogenesis", as the creation of division between individuals or groups of the same culture. It is the result of cycles of interactions where responses are mutually aggravating, either in a complementary way, one part being aggressive and the other submissive (as happens in social class struggle) or in a symmetrical manner, where both parts are equally aggressive (as in an arms race between rival states). From the perspective of complexity, both double bind and schismogenesis are related to the interdependency between parts, and in both cases emergent phenomena can be outcomes of the cycles of interaction. What emerges is not necessarily positive (mental disease or social conflict), but it could be so if the complexity of the process is understood.

Challenges in Reasoning: Abduction, Logical Types, Impredicativity

Complexity challenges our capacities for reasoning: it generates a perplexity which could be summarized in the saying **"the more we know, the less we know"**, because new knowledge also brings new levels of interactions with reality and hence new complexity and unpredictability. This is why thinkers have been experimenting with tools beyond conventional reasoning. One is "abductive logic", which looks for the simplest inference from a set of observations. The process may lead to a logical fallacy (by observing many white swans we cannot conclude that all swans are white), but it can provide useful insights, e.g. starting points for AI algorithms. In practical terms life is full of phenomena defying rationalistic logic, and paradoxes are easily created. To deal with them Bertand Russell proposed a theory of "logical types". It establishes that different logical levels exist: e.g. a class of objects is of a logical type higher than its members and to avoid confusion no class can contain itself as a member. The term "impredicative" was also coined by Russell to designate any object whose definition is self-referential, that cannot be defined without referring to itself.

Life and language are actually full of situations in which circularity leads to confusion, if using ordinary logic. Communication pathologies such as double binds happen because the contradictory injunctions come from domains located at different logical levels. Also, scientific disciplines are built upon the hypothesis that most objects of analysis are predicative: they can be defined by referring to other objects previously defined. But organisms, minds and societies actually produce themselves. Self-organization and auto-poiesis (see 4.5.3) are manifestations of the impredicative nature of reality. More generally the most important things are impredicative: who can explicitly define love or life? If most of relevant things are impredicative, this is no longer an issue. The issue lies in the limitations of our incumbent epistemology in dealing with real-world systems, which are complex and hence impredicative. But this is also a great opportunity to open new avenues for continuing the adventure of knowledge. Complexity is not a further improvement after mechanicism, it is a new beginning.

Levels of Learning

From the perspective of complexity there are different types or levels of learning, corresponding to different levels of abstraction [Tosey et al 2011]. Learning 0 corresponds to the absence of correction of errors and could be qualified as "not learning", but it derives from the learning that stability of behaviour is important. Learning I is about the ability to try different responses within an established set and learn from errors. Higher levels correspond to increasingly higher levels of abstraction in what has to be changed to obtain an appropriate response in a particular situation [Bateson 1972]. In this taxonomy the different levels do not correspond to a hierarchy or a pathway of capacities to be progressively acquired, nor to a segmentation of humans according to their invididual capacities to reach one level or another. Learning modes can happen simultaneously and the range of capacities shared by all children is in this respect are much richer than conventional views of education would suggest [Bloom 1992].

What is implied by this perspective of learning at different levels is that dealing with complexity requires enlarging the sets of responses that can be tried (and the sets of sets, and so on) in constant interaction with whatever we are trying to learn about. Hence the idea that mutual learning (see 2.3) is the best (or maybe the only possible) approach for that purpose.

Automated Knowledge Discovery

"Machine learning" is a set of techniques widely used in the domain of "Artificial Intelligence" (AI). Instead of codifying in a machine what are the rules of intelligence, this approach tries to infer the rules from sets of historical data. Progress in AI is fed by combined advancements in algorithmics, the availability of data and capacities to process huge datasets. AI is being publicized by interested parties and the media (not by the scientific community) as a silver bullet to help us address all kinds of challenges. Part of the hype is based on reality, part on extrapolation, along the following scheme:

- Technical achievements make possible to infer patterns from data related to phenomena of interest;

- These patterns are useful for different analyses: description (what happened?), diagnostics (why did it happen?), prediction (what will happen?) and prescription (how to make happen what we want?);

- The reliability of the analyses makes possible the automation of repeatable tasks and the transfer of responsibility on decisions with no or very little human supervision (e.g. in autonomous vehicles).

In a nutshell, this is about the possibility that we build machines whose capacity to process much more information will make them better than us at implementing tasks and taking decisions. The expectations of what AI could do are clearly exceeding what it actually does. This points to the existence of blind spots (see 4.1.5): some are intrinsic to the underlying techniques, others are in the framing of public debates. Since pattern recognition techniques require huge amounts of data from many different cases to be effective, they are necessarily based on decontextualizing information and discarding interdependencies, in other words on denying the uniqueness of each of our lived experiences. Increasing the quantity of data may help to improve our models but it does not change the reductionist nature of modelling, especially if it discards interdependencies.

Also, machine learning provides statistical regularities but rarely a reasoning nor an explanation of why the regularities exist. And since AI predictions and prescriptions are grounded on the extrapolation of identified patterns, their reliability depends on the stability of those patterns and hence we can expect better results when AI is applied to deterministic phenomena (or close to). But life as a whole is non deterministic, and constant interactions between cognitive agents (humans and non-humans) produce new, unexpected and unpredictable patterns (see 4.5.1 to 4.5.3). Complexity is actually increased by the addition of AI-based artifacts as new cognitive agents in new layers of interactions. Hence AI will not help in controlling the world at large: it may be useful for controllability in local contexts and scales but overall it increases complexity and reduces predictability. This is a fundamental limitation as far as the techno-utopia of a world better managed by AI is concerned. But it also opens the possibility of reframing the development of AI for purposes of RRI in the context of our societal challenges.

4.6.4. Non-equilibrium Thermodynamics

Thermodynamics deals with energy and its ability to be used for work. From non-mechanistic perspectives non-equilibrium is the normal state of systems. Putting equlibrium at the core of many scientific disciplines is a blind spot which prevents us from seeing that systems are naturally dynamic, and only static in exceptional situations. Non-equilibrium thermodynamics builds upon this and conciliates physics and biology, the living with the non-living. The total energy of an isolated system remains constant (principle of conservation) while its quality degradates over time (as measured by entropy). Thermodynamic equilibrium is the destination of that process, in which entropy is maximal

and no work can be obtained. For living systems this means death. In other words, living systems are always far-from-equilibrium. This area of study has been extremely fruitful in the explanation of:
- the essential irreversibility of natural and human processes;
- how ordered structures can emerge out of chaos ("dissipative structures");
- the onset of self-organization, when a system shifts by taking one of the branches emerging from the bifurcation in the vicinity of a critical point [Prigogine & Nicolis 1977];
- the role of threshold conditions and entropy production in that process of bifurcation [Jantsch 1980];
- the essential uncertainty which characterizes all complex systems [Prigogine & Stengers 1997];
- the process of "autopoiesis" (see 4.5.4) by which all living systems are able to maintain and reproduce themselves.

In SeeRRI, this branch of physics provides concepts and criteria which can be used by analogy in the reflections on what can make territorial R&I ecosystems self-sustainable through a perspective of RRI.

4.6.5. Criteria for Self-sustaining Processes

Process philosophy is a fundamental element of theSeeRRI Conceptual Framework (see 2.1). Understanding which processes grow and which decline is a central element of analysis of any kind of system. Moreover, to promote a deliberate direction of evolution it is critical to identify the conditions required for the favourable processes to grow and be sustainable over time. In SeeRRI we use the following criteria [Jantsch 1980]:
- Openness: processes have to be able to exchange energy, resources and information with their environment in order to persist, evolve and adapt while keeping their own identity and singularity;
- Energy: processes are not static, they are embodied in far-from-equilibrium dynamic entities, one of whose characteristics is to capture large flows of energy from their environment;
- Auto-catalysis: to keep the processes alive and thriving, their outcomes have to reinforce certain steps of the processes themselves.

In SeeRRI the concept of "energy" is not identical to that used in physics, but human processes also need to capture energy from their environment, and this can be practically assessed: e.g. forms os "social energy" are financial revenues, time and efforts committed by volunteering individuals (not by employees since in that case the net amount of "energy" is supposed to be zero), new talent attracted, attention captured from society at large, and so on. The evolution of human processes and the structures (organizations) to which they give birth can be analyzed in the light provided by the above criteria. If an organization becomes too closed in upon itself or fails in retaining the flow of energy it receives from its environment, it will soon start to decline. The most important criterion is auto-catalysis: it ensures the exponential nature of process growth. An example is the demographic mechanism: the more children are born in a generation, the faster the population will grow. Another example is the appropriation of economic benefits by the company producing them: the more profitable it is, the faster it can grow if the benefits are reinvested in the company operations.

The SeeRRI approach also selects on which processes, at which levels and considered within which contexts it makes sense to focus the actions to promote RRI. A specific selection of contexts is made to make the Conceptual Framework operational (see 2.2.5). As far as the large-scale transformation of R&I ecosystems is concerned, we build from the hypothesis that RRI-based processes have to grow and populate the domain of R&I activities faster than those ignoring RRI.

4.6.6. The Mistery of Life: Emergence from Emergency

"Life is a game whose purpose is to discover the rules, which rules are always changing and always undiscoverable" Gregory Bateson (*"Metalogue: About Games and Being Serious"*)

This subsection closes the Thesaurus part of this report (see full version in Annex). Many concepts from the best of systems and complexity thinking have been explored to bring light to the challenge of promoting self-sustaining R&I ecosystems informed by RRI in territories. The ways these concepts are used to build and apply the SeeRRI Conceptual Framework have been described in Sections 2 and 3.

A major conclusion is that **we do not understand reality, we just build frameworks of interpretation through which we try to explain what we perceive of reality**. And this process can be misleading, it produces blind spots (see 4.1.5). But at least we know we have blind spots, and that makes a big difference.

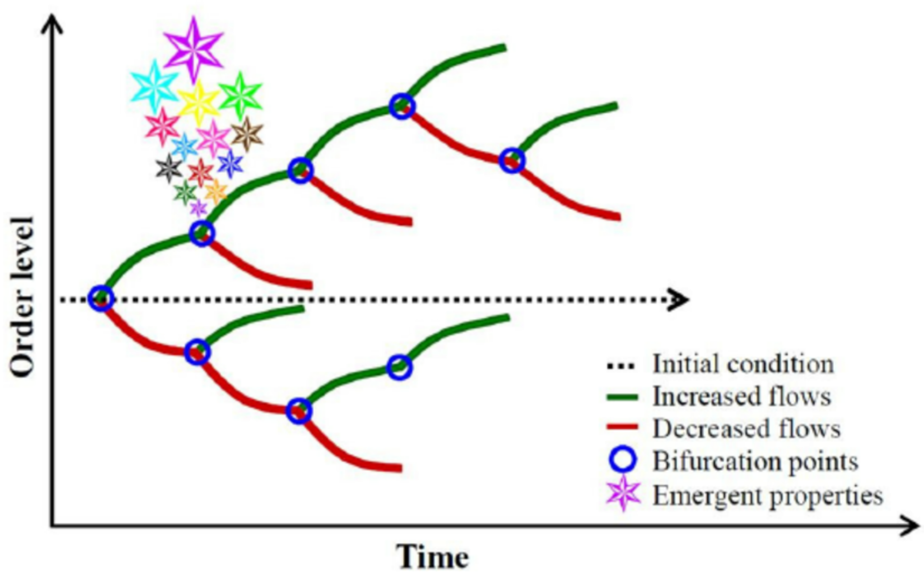

Figure 27. Bifurcations in dynamical systems (source: ResearchGate)

Most probably we will never complete our understanding of the mystery of life [Morin 2017]. But an important fact is that critical points are ubiquitous: all kinds of dynamical systems, especially living ones, go through situations in which they can shift from one state to a completely different one through complex processes of "bifurcation" (see figure 27). To follow the description by Erich Jantsch:

> *"**The essential feature** is the internal reinforcement of fluctuations (by autocatalysis) which eventually **drives the system over an instability threshold into a new structure**. (...) the **principle of creative individuality** wins over the collective principle in this innovative phase. (...) However, it is not predetermined which structure will come into being. At each level of autopoietic experience, **a new version of macroscopic indeterminacy comes into play**. The future evolution of such a system cannot be predicted in an absolute way; it resembles a decision tree with truly free decision at each branching point."* [Jantsch 1980]

Life has been evolving and innovating during millions of years and taking into account the results, we should humbly recognize that our own capacity to innovate is comparatively limited: nature is able to produce a countless number of viable forms of life by using very few materials and producing no waste. Also, a non-reductionist interpretation of the theory of evolution shows that competition may play have a very limited role, collaboration is more the rule than the contrary [Weizsäcker et al 2018].

As announced by many thinkers, we humans are now at a turning point in the history of civilization: it is time to bifurcate, to **emerge into a substantially different type of organization from the many emergencies in which we are involved**. But emergence does not happen through a smooth and painless transition, it unfolds in critical situations created by painful emergencies during which the outcomes are not predictable nor guaranteed in any way. As repeatedly said, there is no other way to go through the process of emergence than by climbing a steep ladder of mutual learning. But we do not build from scratch. We can use ideas derived from a careful observation of natural intelligence, expressed e.g. as follows, in the form of 10 rules governing how all life works [Gorissen 2020]:

> *"there is no taking without giving;*
>
> *it takes an ecosystem to sustain an ecosystem;*
>
> *interdependency rules; nothing occurs in isolation;*
>
> *the byproducts generated are as fundamental to evolution as the innovations themselves;*
>
> *diversity, decentralization, and redundancy build resilience; monocultures and monopolies build brittleness;*
>
> *keystone species create favorable conditions; conditions that enable regeneration from the bottom-up;*
>
> *it is the avoidance of competition that drives evolution;*
>
> *invest in the health of others to ensure your own;*
>
> *leave it better than you found it;*
>
> *never take all."*

As Leen Gorissen concludes, *"the nature of the future and the future of nature are interdependent".*

POSTFACE: SYSTEMS THINKING AND RRI IN TIMES OF COVID-19

Writing this Report in Spring 2020 makes impossible to ignore the situation created by the worldwide propogation of virus Covid-19 and its consequences. As with many other activities it has disrupted the execution of SeeRRI itself. Not to the point of putting the project in danger, but the calendar had to be reassessed and all on-site activities had to be either postponed or moved to teleconferencing platforms. Depending on the evolution of the pandemic in coming months it remains to be seen how the planned activities with stakeholders will be carried out. In comparison with many other contexts these are small perturbations, but relevant enough to provoke some thoughts, especially in a project based on the responsibility of research and innovation.

From a systemic perspective the Covid-19 situation raises many considerations and questions, potentially fruitful. We summarize here a number of them.

Systemic fragility. Viruses are tiny and elementary pieces of biological material, among the most primitive tokens of the existence of life on Earth. And still, a particular kind of virus has been able to fully destabilize our globalized and highly technological civilizations. For all the arrogance our knowledge and capacities have given us, there seems to be a huge disproportion between our perception of modernity and our fragility in front of nature. We should learn a lesson in humility.

Interdependencies. The impact of Covid-19 has been what it is not because of the virus itself, but due to the combination of many factors showing how interdependent we are. From a systemic perspective there is nothing new here, reality and in particular life are woven of interdependencies (see 3.2.5 and 4.5.2). But one lesson we could take is that complexity is relevant and feedback loops are everywhere. Without the increased pressure and destruction of natural habitats zoonoses (transfers of viruses from wild animals to humans) would be much less frequent. Without the generalized patterns of mass urbanization in cities with poor air quality, propagation of the virus would have had less impacts. Without globalized infrastructures the worldwide propagation would have been slower (see the moderate impacts in most Asian countries who closed their borders to travels from/to China by end of January). And so on. Interdependencies are extremely relevant.

Framings. As discussed in 4.1 we do not deal directly with reality, we elaborate frameworks to make sense of our perceptions. This is particularly true when facing a pandemic, in which our perceptions are not so useful since we do not see the virus (although we represent it abundantly). The easiest framing is that of the "war on virus", pretty much as we declared the "war on cancer" (see 4.1.4) and many others on issues related to health ("war on drugs" and so on). This military framing is deeply misleading. The virus has no intention of attacking us and we cannot "win" this "war". Viruses were part of the primeval environment from which life emerged on Earth and their number is estimated to be 22 orders of magnitude larger than the number of humans. There is simply no way that we can even fight, not to say win, a war on viruses. The best we could do is to take measures to avoid its propagation, mobilize the resources to deal with the sanitary emergency, and try to understand better the sickness provoked by the presence of the virus (when it happens).

Another common framing about Covid-19 has been to look for culprits, in the form of multiple conspiracy theories (mainly against China) and blaming of incumbent governments. Very rapidly the deadly effects of the pandemic have been associated to a poor "management", and rankings of countries and benchmarkings of leaderships have been produced. While of course decisions taken by governments have played a significant role, this overestimates the role of human agency and shows that we have difficulties in accepting complex chains of causality. Among others, the state of healthcare capacities of a country and the quality of public health monitoring have been probably more relevant than the concrete decisions taken during the pandemic. But other factors are relevant as well.

Converging factors. At this stage we already know that contagion is not widespread (around 5% of the population in Spain in first weeks of May), but large enough to be sure that it is one order of magnitude higher than the number of declared cases (Spain: seroprevalence around 2 M people, declared cases around 250 k people) and that the overall mortality rate is in the order of magnitude of 1% (again, based on data from Spain, one of the most affected countries). So, it seems obvious that the presence of the virus by itself is not enough to cause major loss of life (unlike other viruses like Ebola, with a much higher mortality rate). Converging factors must be in this case extremely important. Air quality is probably one of them, since it can be the cause of previously high levels of respiratory diseases, especially in urban populations of seniors. Again, this points to complexity.

Unexpected? In recent weeks we have frequently heard that nobody could have imagined the situation in which we are. It was not only imagined but anticipated and actually occurred many times in history. The record of pandemics goes back at the very least to the Plague of Athens in 5th century BCE. Moreover, the pace of new epidemics (mostly coming from zoonosis) has accelerated in the last decades (e.g. HIV/AIDS, avian flu, swine flu, Ebola, SARS, and so on). Alarms were repeatedly raised about the possibility of a pandemic of the kind we have now. SARS got close to becoming one. We simply had a blind spot on this, we preferred not to acknowledge what we already knew.

The role of science. One substantial difference in this pandemic is the role of digital media: it has facilitated the large mobilization and effective cooperation among scientists, as well as a high degree of instant awareness of what is going on and the participation of concerned citizens (including the dark side of it: fake news and so on). High anxiety is naturally focused on the discovery of a vaccine or effective treatments. But when looking at lessons learned from previous epidemics, one of the conclusions is especially disturbing: *"twenty-first century science played a relatively small role in controlling SARS; nineteenth-century techniques continued to prove their value"* [Chew 2007]. This requires further investigation, but it could be that the progress of science in this area is being limited by epistemological barriers.

Responsibility. There are many levels in which responsibility can be considered. A basic one is to avoid the propagation of the virus as much as possible, which for individuals means following the restrictions and recommendations imposed by governments (confinement, social distancing, wearing masks, hygiene). But there are other levels, which have led very quickly to the double bind of "death or economy"? This looks like a "zugzwang" (a situation in chess where all moves are bad). If one reopens activities too fast there will be more contagion and deaths from Covid-19. If too slow the economy will continue to suffer, creating harmful social consequences (including the psychological effects of long confinement). It is difficult to find an optimal trade-off between both injunctions.

Bifurcation. At the beginning of the emergency situation it was quite common to take it as a parenthesis and that we would come back pretty soon to "normality", to "business as usual". But time passed and months later, in the absence of effective treatments we are not yet seeing a return to the prior status quo. It could be that Covid-19 is another manifestation of the critical zone in which human civilizations have entered (see 3.4 and 4.6.6), and that it is not leading us back to where we were but rather to a bifurcation. One emerging scenario is that of an inhuman life, in which we are all converted into frontline soldiers of the war on virus and other threats. It is a scenario of fear, in which we wear masks and protections to avoid contagion and we keep our distances from others and life at large, in order to keep in "good" health and working to earn a life. Hopefully, other scenarios will slowly emerge.

What is essential? Among other things, confinement could also be taken as an opportunity to reconsider some basic questions, and in particular what makes our life worth living. Responses to that are very personal, and no doubt that confinement has created a lot of frustration for good reasons. But it has also made people rediscover the value of solidarity and caring for one another, as well as the importance of millions of jobs, poorly paid and deemed as "unqualified", without which we simply cannot live. And in a period when consumerism was put to an halt and restrictions were impeding many ordinary activities, the value of creativity was also emphasized. These may be good lessons of the crisis.

Transformative resilience. To conclude with a positive note, there is another branch out of the bifurcation of Covid-19. It is about *"bouncing forward"*, creating the opporunity to make the most of our recovery from the hardest part of the emergency. In other words it is about substituting "recovery" by "transformation" towards the kind of societal arrangements that are needed to deal with the many self-inflicted existential threats we face. Covid-19 has shown that we are perfectly able to shift our behaviours instantly if there are good reasons to do it. Now we have to keep that in mind to understand that Covid-19 may have been the revealing factor of our biggest blind spot, that which makes human development incompatible with a healthy biosphere. In an EU context, this means accelerating the deployment of some policies and initiatives which already existed, such as RRI and the European Green Deal, in order to emerge from the crisis through the branch of *"transformative resilience"* [Giovannini et al 2020]. This beautiful and necessary oxymoron shows the way to a society of caring for one another and for nature, a constellation of places where equitable wellbeing at peace with a healthy biosphere is made real.

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Annex to D4.1 - Thesaurus and Conceptual Framework of Self-Sustaining R&I Ecosystems

Work Package: WP4 – Development and Validation of an Integrated Framework

Annex v1.1

Lead beneficiary: Fundación Instituto de Investigación Innaxis

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LIST OF FIGURES

LIST OF TABLES

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Description of the deliverable	This document is an annex to D4.1. It contains an extended version of the Thesaurus of concepts whichs is part of the outcome of Task 4.2.
Key words	Conceptual framework, systemic thinking, R&I ecosystems, cybernetics, complexity, wellbeing(s) in the biosphere

DOCUMENT HISTORY

NAME	DATE	VERSION	DESCRIPTION
Annex to Thesaurus and Conceptual Framework of self-sustaining R&I ecosystems	8/6/2020	1.0	Separation of annex from D4.1
	16/6/20	1.1	Addition of lists of figures and tables and final formatting

EXECUTIVE SUMMARY

This document is an annex to the report D4.1 "Thesaurus and Conceptual Framework of Self-Sustaining R&I Ecosystems". D4.1 presents the outcomes of SeeRRI Task 4.2 "Framework for a self-sustaining ecosystem", whose objective is to produce a Conceptual Framework to be used in SeeRRI itself and in other initiatives in the future. SeeRRI uses a conceptualization of R&I activities based on a systemic perspective and state-of-the-art thinking from process philosophy, complexity theory, cybernetics and ecology, among other disciplines. References to these diverse disciplinary groundings are compiled in the form of a Thesaurus: a repository of 34 concepts or conceptual areas whose descriptions can be useful to the reader in a multiplicity of contexts. D4.1 contains an abridged version of the Thesaurus, which is presented in more detail in this annex. The particular set of concepts is the result of an elaboration, not only by taking pieces of academic knowledge from here and there but also by sharing backgrounds, practices and questions among SeeRRI partners and territorial stakeholders in workshops and project meetings during the first 15 months of activity of the project. The Conceptual Framework is the current endpoint of a journey which has been collectivelly travelled during that period, not necessarily in a linear way. Our roadmap is represented here (see figure A1) and integrated in D4.1 and this annex through the six sections in which the set of 34 concepts is divided.

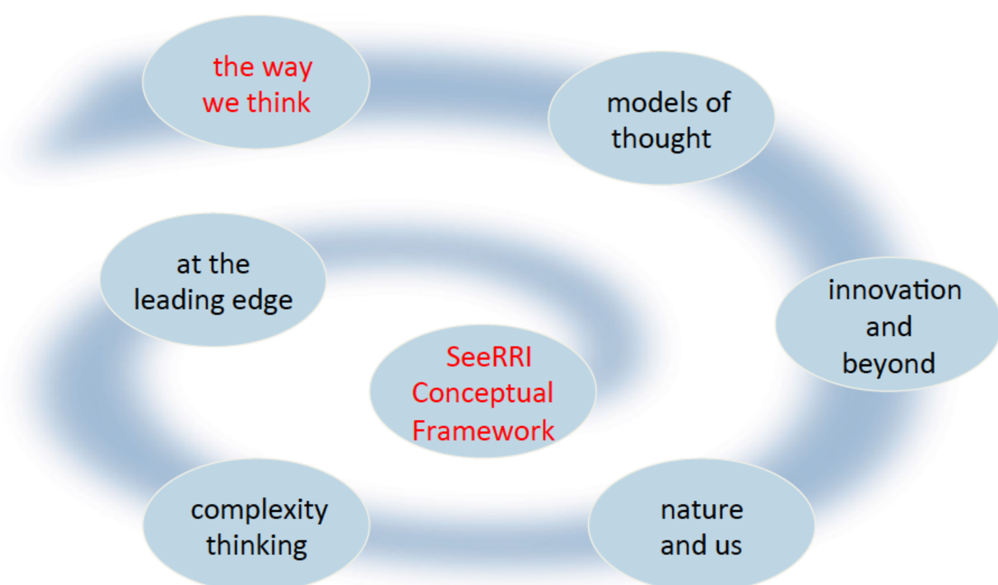

Figure A1. The spiral roadmap leading to SeeRRI Conceptual Framework (source: own elaboration)

In this annex references to the main document D4.1 are presented with prefix "D".

A1. THE WAY WE THINK

A1.1. FRAMEWORKS

There are many definitions of what a framework is, especially coming from engineering and software development domains. They have in common the idea that a framework defines and structures a certain number of concepts and rules as a common ground for the development of a project, or a series of them. In that sense, a framework is useful inasmuch it provides a common understanding of a number of elements shared by different parts of a project or different projects, without having to redefine them every time, and hence increasing productivity as well as preventing inconsistencies. Sharing a common framework is particularly useful when different disciplines contribute to a project: it can facilitate inter- and transdisciplinary approaches.

In a slightly more general way, we propose to use the following definition:

> *a **conceptual framework** is a set of organized assumptions which frames the analysis on a specific matter and is useful to create knowledge, implement deliberate actions and deliver outcomes in a systematic manner, in particular in the course of a project, or a series of them.*

SeeRRI works at the confluence of two policies of the European Union, namely Responsible Research and Innovation (RRI) and Regional Research and Innovation Strategies for Smart Specialization (RIS3). Both policies have developed their own frameworks and best practices.

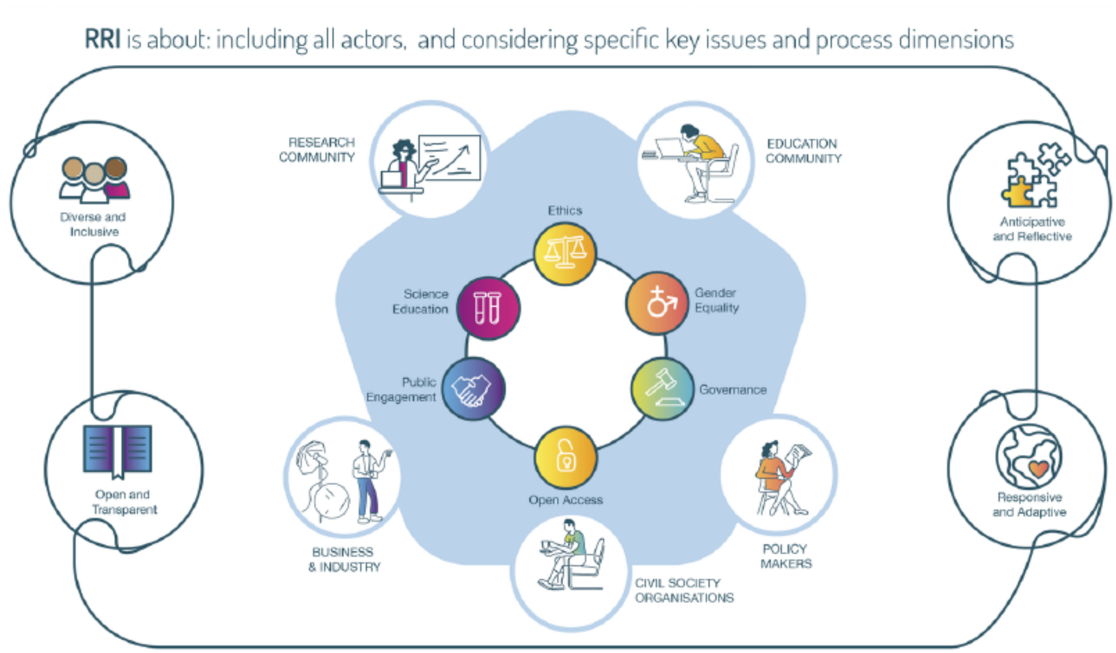

Figure A2. RRI Operational and Process Dimensions in Multi-Stakeholder Contexts (source: SeeRRI)

In the case of RRI, as represented in figure A2 above, a number of Operational Dimensions have been identified: Gender Equality, Ethics, Open Access, Public Engagement, Science Education and Governance. Through this framework, the promotion and adoption of RRI started as a process of compliance at the level of each individual organization involved in R&I activities. At the same time, Anticipation, Reflexivity, Inclusion and Responsiveness were as well identified as desirable characteristics of R&I activities, within and across the organizations involved in them [Stilgoe 2013]. These are the Process Dimensions of RRI. Both Operational and Process frameworks are different but not incompatible.

Also, as represented in figure A3, RIS3 smart specialization strategies have been framed in a 6-stage cycle, from Analysis to Monitoring and on [Foray 2012].

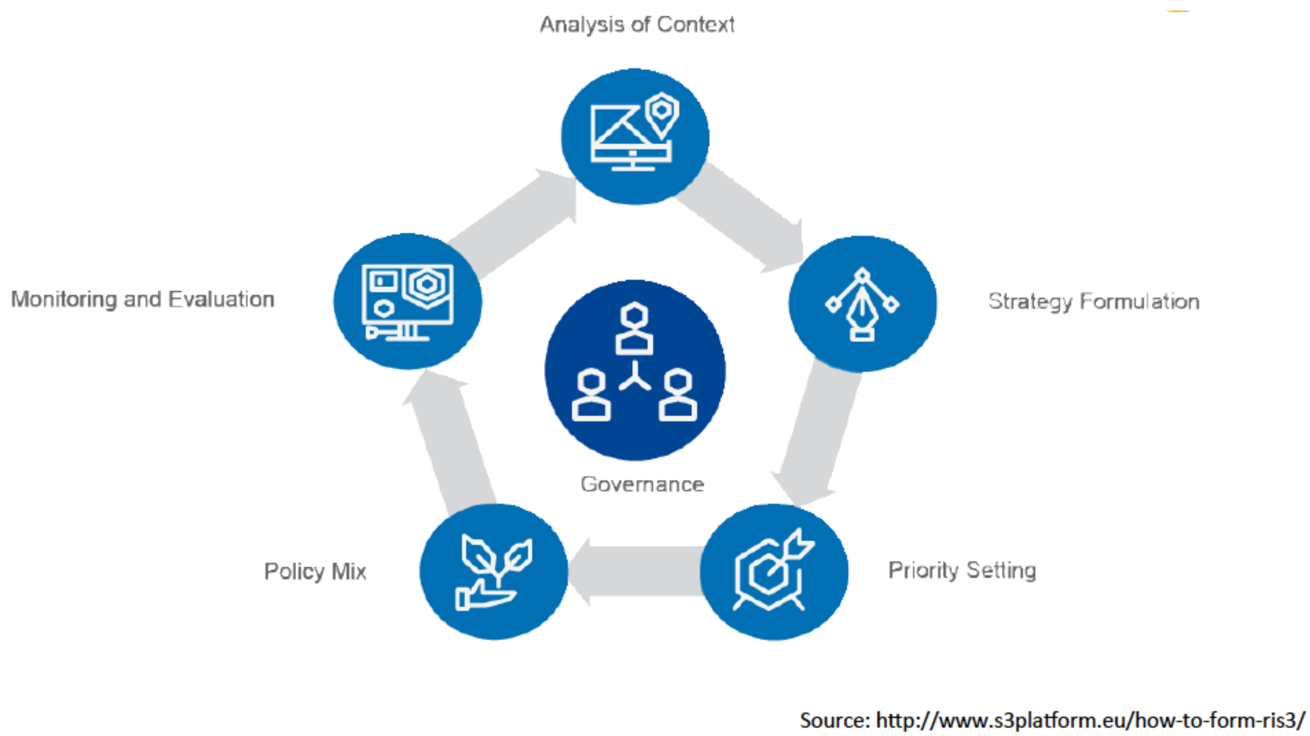

Figure A3. The multi-stage framing of RIS3 (source: S3 Platform)

And coincidently with the explicit goal of SeeRRI and other projects to facilitate the integration of RRI and RIS3, at least one framework has been defined for that purpose [Fitjar et al 2019]. It is presented in table A1.

Table 2. Integration of responsible innovation and smart specialisation processes — R. Dahl Fitjar et al.

		RIS3 Stages of the smart specialisation process					
		Analysis	Governance	Vision	Prioritisation	Policy mix	Monitoring
Dimensions of RRI	Anticipation	Identify societal needs	Identify all potential stakeholders	Consider potential negative or unintended outcomes	Consider impact of priorities on social and environmental outcomes	Consider unintended outcomes of policy	Evaluate broader effects, beyond narrow policy aims
RRI	Reflexivity	Reflect on value system on which analysis is based	Consider potentially diverging interests and reflect on differences in power	Allow for different perspectives on vision for future	Reflect on impact beyond the represented stakeholders—and beyond the region	Reflect on diverging interests for different policy mixes	Reflect on value system of evaluators
	Inclusion	Engage stakeholders in analysis	Include a variety of stakeholders in management	Include a variety of visions and opinions	Have an open process around prioritisation where different voices are heard	Keep policy-making in democratic for a	Include stakeholders in evaluation
	Responsiveness	Respond to new knowledge and other perspectives	Respect all opinions, including from minority and less powerful groups	Be responsive to critical concerns about the vision	Allow for criticism of prioritisation and accept that chosen priorities may be wrong	Let dissenting voices be heard	Allow for change in evaluation criteria and results in response to feedback

Table A1. Framework for integration of RRI and RIS3 [Fitjar et al 2019]

In the domain in which SeeRRI works there is no lack of conceptual elaborations which can be used as frameworks. Why does SeeRRI consider that an additional framework is needed? First, let us state that our framework does not displace or cancel the existing ones. Rather, it builds on them, especially on the Process Dimensions of RRI. But it goes beyond what is proposed by previous frameworks because it poses different questions, and from a different perspective. The main question is how to create a self-sustaining dynamic at the level of regional R&I ecosystems evolving towards full responsibility. The perspective is that of systems thinking and in particular of complexity theory. This requires looking at the interdependencies between the multiple actors intervening in R&I ecosystems at multiple scales. We make two statements:

- Regional R&I ecosystems of actors are complex systems, they do not fit into linear, mechanistic descriptions of how social processes take place,

- The conjunction of RRI and RIS3 is itself a process of learning and transformation which cannot be effectively planned in a purely linear way.

This document elaborates these hypotheses. Our approach recognizes that we do not make conscious interpretations of reality without the intervention of a framework, which assigns concrete meanings to our perceptions (see A1.3). The framework literally “frames” how we think about a subject and in particular what questions we are able to ask about the subject, and hence it conditions the way we learn about it and develop our analysis and actions. The SeeRRI Conceptual Framework is a "question machine" based on a state-of-the-art understanding of how complex systems learn and evolve.

A1.2. EPISTEMOLOGY

Going back to the definition of a conceptual framework stated in A1.1, the main aspect to address is how useful the framework can be to create knowledge on a specific matter and as a consequence implement impactful actions. In our case the matter is the deployment of RRI principles in regional R&I ecosystems with the goal of making them both responsible and self-sustaining.

At first, the idea that knowledge creation depends on the framework through which we analyze reality may seem strange. Do we not already have all the scientific methods and tools to obtain knowledge from reality? Is true knowledge not an "objective" matter, an object whose substance does not depend on the pathway to attain it? The existence of these questions is the reason for the existence of epistemology, as the branch of philosophy dealing with the creation of knowledge. It studies the nature of knowledge and its relationship with truth, belief and justification, as well as the practices, rules and conditions applying to the process of creation of knowledge. The term is relatively recent: used for the first time in English in 1847 in a translation from the German word "Wissenschaftslehre" (meaning literally the "theory of science"), it is based on ancient Greek "epistēmē" (meaning "knowledge") and the suffix "logos" (meaning "discourse"). While the word is recent, the concept is not and the investigation of the nature and creation of knowledge is part of all philosophical traditions.

Over time, questions addressed have evolved: Plato was interested in understanding what it was to know and why knowledge is better than opinion, Kant explored the conditions of the possibility of human understanding, and Russell's inquiry was about how modern science could be justified by sensory experience. More recent works (e.g. feminist epistemology) are attempts to understand how our preconceptions affect not only our understanding but also the evidence we use [SEP 2005]. The abundance of work in the field has made that the word "epistemology" is also used to designate each of the different theories, not only the discipline as a whole.

In Western tradition and practice the three following domains of thought have been distinguished:

- Ontology, considering reality as what truly is in essence,

- Epistemology, considering our understanding of reality and the creation of knowledge,

- Ethics and purposes, considering the course of our actions and what should be.

The idea that these dimensions can be separated has been foundational to our modern civilizations and has also framed the separate roles of social domains (see figure A4): positioning ourselves as external observers, we think that science is a suitable bridge between ontology and epistemology, it enables us to improve our understanding of the essence of reality. The mediation between epistemology and ethics is assigned to two domains mostly disconnected from each other. On one hand, law and the design and development of social institutions are deemed to embody the values and principles for a society combining individual aspirations and the common good. On the other, technology, business and innovation have become key instruments in our attempts to acquire applied knowledge and transform reality, intentionally also for the better (whatever this could mean in each context). It is interesting to notice that to a large extent art and religion are excluded from this scheme. Intuitions of the unknowable, the construction of our social emotions and access to aesthetics are considered to be matters separate from the rationalistic arena where understanding and knowledge creation and use take place. Actually, art and religion have been not only separated from science, technology and law, but also increasingly confined to private spheres.

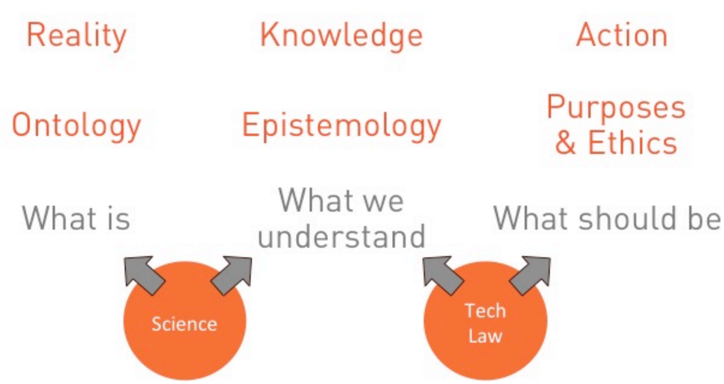

Figure A4. The conventional separation of domains of thought (source: own elaboration)

This and other schemes based on separation have been a fundamental element of how modern societies emerging from the Scientific and Industrial Revolutions have been thinking about themselves, and consequently acting. The splitting of knowledge into different and mostly isolated disciplines is a case in point. Another is the organization of governments into different ministries dealing in parallel threads with inevitably intertwined realities. The world we know today is built on the assumption that splitting everything into parts works fine for both individual and collective wellbeing.

Why is this relevant in the context of RRI and the Conceptual Framework for self-sustaining R&I ecosystems? Firstly, the requirement of responsibility in research and innovation introduces or makes explicit in our analysis some questions directly related to epistemology. Is the responsibility of knowledge itself not a matter of concern? Does the nature of knowledge make it "objective", beyond the reach of human passions and miseries, and then the issue of responsibility affects only the use of knowledge? But also, what makes that a process of knowledge creation can be considered as responsible? [Kunneman 2010]. As these questions show, the recent development of the concept of

RRI is itself an epistemological endeavour, a reflection on the nature of knowledge and the quality of the process by which knowledge is created.

Secondly, the splitting operation mentioned above as a fundamental aspect of conventional Western epistemologies (addressed in more detail in Section 3) is not appropriate if our object of analysis is an ecosystem, where interdependencies are the key to the overall behaviour. Inasmuch we pretend to analyze R&I activities from an ecosystemic perspective, and not only in a metaphorical way, we need to consider other epistemologies. The evolution of science shows that whenever a certain epistemology proved inadequate to explain evidence, conditions were building up for an epistemological leap to a new framework or paradigm [Kuhn 1962]. This has been particularly the case in the domain of physical sciences [Fiorini 2018]. While SeeRRI is not going to develop its own epistemology from scratch, it needs to build upon perspectives of knowledge consistent with RRI and the idea that entities and processes of R&I actually form ecosystems, at different geographic scales. A good point to start elaborating on that need is to address the issue of how knowledge is related to perception.

A1.3. PERCEPTION AND COGNITION

Figures A5 and A6 below show very simple examples of how perception does not necessarily lead to cognition.

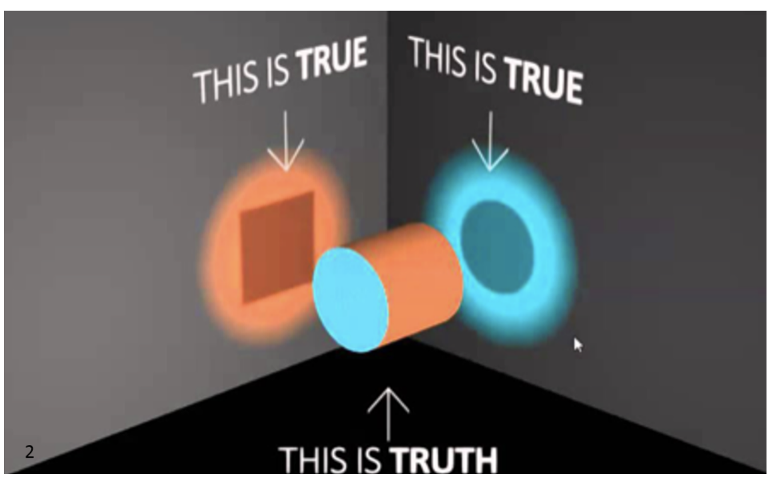

Figure A5. The incompleteness of partial and contradictory truths (source: Jacques de Gerlache)

While figure A5 is about the incompleteness of knowledge we can derive from our perception if we do not take different perspectives *at the same time*, figure A6 is about the possibility that a proposition could be true and false *at the same time*, which defies conventional reasoning (see A6.3.3).

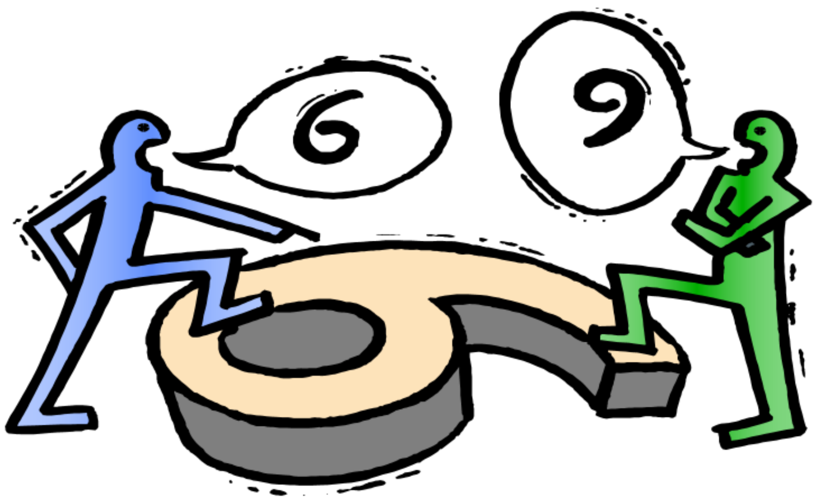

Figure A6. Points of view simultaneously right and wrong (source: Jacques de Gerlache)

Both figures are about the dimensionality of knowledge and since they deal with two and three dimensions, i.e. within a geometric domain that we can grasp perfectly well, it is easy to see how to complete the framework of observation to obtain all the knowledge which can come out of them. Which does not mean it was always easy for humanity to perform the shift. The discovery that the Earth is not flat or the Copernican paradigm shift from the Ptolemaic Earth-centric model of the heavens to an heliocentric one fall into this category: a flat Earth or the Ptolemaic model were consistent with most of our perceptions but they were incomplete truths which are now located into larger pictures of the universe.

But many questions of interest in the real world are not that simple, in terms of dimensions. If we assume the perspective of complexity (see A5.1), we have to accept that interdependencies are the key of any relevant matter and hence infinite dimensionality is always around the corner. In other words, complexity thinking starts by assuming that in first approximation things happen as if everything was connected to everything else. This is not the way we usually think, rather its opposite, and we struggle if we have to deal mentally with high dimensionality. Our way of doing science is most of the times influenced by the "law of parsimony" or "Ockham´s razor" (named after 14th century philosopher William of Ockham), i.e. the idea that *"entities should not be multiplied without necessity"* or in other words that *"the simplest solution is most likely the right one"*. Which is powerful if it works, but what if not? An Earth in the center of the universe is the simplest explanation until one realizes it is wrong. Over last decades cognitive science has developed many different approaches to improve our capacity to derive knowledge from our perceptions, navigating between the two poles of simplicity of explanation and infinite dimensionality of most of relevant questions. Among the techniques nowadays used by the domain of Artificial Intelligence (AI), "machine learning" combines data extraction and computing capacities in order to deal with much higher dimensionality than usual when trying to obtain knowledge from a massive collection of perceptions. At the same time, classical AI, generative syntax, functional imagery-based cognitive neuroscience, evolutionary psychology, action-based theories of perception, signal detection theory, formal learning theory, to mention but a few examples, continue to be *"special branches of, and (controversy-provoking) paradigms within, cognitive science"* [Andler 2005].

The above examples and reflections show that our conscious mind does not have a direct access to reality. The access is mediated by our perceptions through multiple channels of communication, most of them unconscious. Our mind makes sense of the flow of perceptions through frameworks of interpretation. This is an area of investigation very much alive, whether considering basic issues of neuroscience such as memory [Gilboa et al 2004] or the influence of social interations on the relationship between mind and reality [Jussim et al 2005]. Overall it could very well be that the best knowledge we can obtain about reality at a given point is just plausibility and that, even supposing that the human mind gets closer and closer to reality it will never reach it [Popper 1972]. For the purpose of this document, let us just retain that frameworks of interpretation play a fundamental role in the construction of our conscious understanding of reality (what we usually call "knowledge", see fig A7).

Reality | Perceptions | Frameworks of interpretation | Conscious understanding

Figure A7. Mediations between reality and understanding (source: own elaboration)

At the same time, our mind is not blind to this, so we are able to consciously question how we think about a specific subject. This is the essence of second-order cybernetics and reflexivity as a characteristic which is required in RRI (see A6.2). This reflexivity starts by identifying the contours of the frameworks of interpretation we are using, and making explicit what is usually implicit. This is exactly what we will do in order to build SeeRRI Conceptual Framework: elaborate and make explicit its main underlying assumptions. These will be statements translating our understanding of the domain in which we work and the ambition of what we pursue. But is there a simple relationship between the conscious adoption of a purpose and the framework required for that purpose to be fulfilled?

A1.4. CONSCIOUS PURPOSE

According to a frequent way of reasoning, if we want to achieve an explicit goal (e.g. deploying RRI practices across R&I ecosystems), the first step consists in consciously defining that goal in a precise way, then identifying a path of purposeful steps towards the goal and completing our arrangement with a set of indicators meant to measure the degree of achievement of the goal. By doing this we are adopting, consciously or not, a certain framework to formulate what we intend to do in a "problem-solution" mode with a linear perspective: we know where we are and we define where we want to go, it is just a matter of taking the steps forward. It may look natural, but it is based on a certain epistemology, that of "conscious purpose". This implies first that we put ourselves as external observers of the system which we want to change. And second that we have the capacity to perform a number of operations on that system which will make it to change in the desired direction. This is correct in many ordinary actions in ordinary life but may be problematic when we intend to change a complex system.

Conscious purpose is many times invoked as a necessity when dealing with complex challenges of society. A case in point is the "War on Cancer", as it was framed at the times of the creation of the National Cancer Act by the US Nixon Administration in 1971. It was a deliberate effort not only to fund research on cancer but to defeat it in a specific time frame, the expectation being at the time that a cure for cancer would be found by the end of the century. And it was framed as a straightforward "moonshot" mission, as President Nixon explained in his State of the Union Address in January 1971:

> *"The time has come in America when the same kind of concentrated effort that split the atom and took man to the moon should be turned toward conquering this dread disease. Let us make a total national commitment to achieve this goal."*

This conscious purpose did not fail completely if we take into account the progress in understanding cancer biology, risk factors, treatments and prognosis of some types of cancer. Though, many types of cancer remain largely incurable, and they are the second most common cause of mortality in the world after cardiovascular diseases. More important here than the appreciation of how much the initiative succeeded or failed, is a reflection on its framing and how this influenced the way the investigation on cancer was conceived. There is some consensus today that the obstacles preventing discovery of a cure for cancer come from its inherent biological complexity which manifests in many ways (numerous risk factors, complexity of cellular interactions, number of changes leading to the cancerous state, heterogeneity of the disease, etc). This leads some researchers to propose complexity-oriented framings for further progress [Jupp 2018]. A second element of relevance is that many of the advancements related to cancer actually came from the investigation of the genome, an example of curiosity-driven research oriented to increase our knowledge of life at large rather than a purpose-driven endeavour oriented to cure specific diseases.

Third but not least, framing a human initiative in war-like metaphors is an action of conscious purpose, but a very specific one, that of declaring an enemy and defeating it, generally by destructive means. This metaphor is again being used with Covid-19. Maybe the changes we would like to induce in a complex system (e.g. a human being immersed in society and the biosphere) will not happen in that way. All cancer drug therapies have in common that they seek to kill cancer cells and they essentially fail to cure cancer [Huang 2014]. By choosing the wrong framework we pursue our goal in the wrong way. This could be related to the excess of "conscious purpose" in our framework:

> *"Consciousness operates in the same way as medicine in its sampling of the events and processes of the body (...). It is organized in terms of purpose. It is a short-cut device to enable you to get quickly at what you want; not to act with maximum wisdom in order to live, but to follow the shortest logical or causal path to get what you next want."* [Bateson 1968]

We reason within our consciousness, so we cannot escape from it. But it can make us aware of its own shortcomings. One of them is to ignore the systemic nature of reality whenever we need to achieve an immediate and urgent goal. But when the nature of the goal is itself systemic (as it is in SeeRRI), it seems better to integrate that characteristic in the framework we use. Doing otherwise would make us victims of our blind spots.

A1.5. BLIND SPOTS

As stated in A1.3, there are gaps between reality and the conscious "understanding" we elaborate. The physiological "blind spot" is the point of entry of the optic nerve on the retina, which by construction is insensitive to light and hence creates an obscuration of the visual field. As a metaphor, we could say that we have blind spots in our observation of the world and of ourselves, which prevent us from seeing aspects of the reality we have just in front of us. The blind spot in the retina has no such consequences because it is surrounded by areas of vision. But blind spots of perception can produce shortcomings in our understanding, especially when they are produced by our unwillingness to see certain aspects of reality. From the point of view of cybernetics (see A2.5), human beings as well as societies and ecosystems are self-corrective systems:

> *"They are self-corrective against disturbance, and if the obvious is not of a kind that they can easily assimilate without internal disturbance, their self-corrective mechanisms work to sidetrack it, to hide it, even to the extent of shutting the eyes if necessary, or shutting off various parts of the process of perception."* [Bateson 1968]

Possibly the first and crucial blind spot is to think that we do not have blind spots, that our access to reality, even if imperfect and incomplete, is nonetheless objective and continuously improving. This idea is built in the approach described in figure A4 (see A1.2), but it could very well prove false. Also, we look for coherence in our interpretations of reality while this is a blind spot in itself: the hypothesis that reality has to be coherent according to what we consciously consider as coherent has been strongly challenged by the developments of physics in the 20th and 21st centuries [Fiorini 2018]. In addition we only give the status of "knowledge" to what we can consciously and explicitly express through the languages we have created ourselves in historical processes full of contingencies, while, as Ilya Prigogine said, *"the world is richer than it is possible to express in any single language"*. In our limited ways of knowing we can only address reality through the words and concepts we have [Jacobs 2014]. It is another blind spot to believe that we have words for everything.

Let us mention an additional type of blind spot, of particular relevance. It is derived from the way we draw the borders of the systems we would like to analyze (and possibly control or transform). From a social perspective, an almost universal principle of organization is to establish who are "Us" and "Them". But this distinction ("you and us are not the same") easily drifts into separation ("we do not depend on you") and ultimately exclusion ("we do not care about you"). This fantasy of exclusion is frequently used to build artificial or real walls, to treat Us and Them with different codes of conduct, an appropriate framing to justify exploitation. Going way beyond distinction, exclusion is ingrained as a blind spot in our mental frameworks. When applied to the analysis of complex systems, this easily evolves into drawing a solid line between us and the system, so that we can imagine ourselves as external observers and analyze, understand and control the system from the outside. This operation is part of the mechanistic way of thinking (see A2.1) but is not necessarily appropriate for all purposes.

Our consciousness makes us aware of its shortcomings. The equivalent of the solution to the physiological blind spot is not built into our mental frameworks, it requires attention and the development of a specific kind of thinking, as described in Section A2.

A2. MODELS OF THOUGHT

A2.1. MECHANISTIC THINKING

As discussed in A1.3, there are good reasons to state that gaps exist between what we call reality and the knowledge we can obtain about it. We can assume that reality feeds the perceptions transmitted by our bodies and instruments of observation. But we do not give coherence and meaning to these perceptions without using, consciously or not, certain frameworks of interpretation. The idea that through observation we can obtain objective knowledge of reality is in itself an interpretation, derived from a particular paradigm of knowledge firmly established in the times of the Scientific Revolution of 17th and 18th centuries, and mainly nurtured by the successful development of classical mechanics and other scientific disciplines. That success did not materialize only at the theoretical level, it has been the foundation for a myriad of practical applications, many of which already existed before the emergence of mechanics as a science (e.g. large buildings, clocks, mills, printers, artillery, and so on) but which greatly benefited and expanded in scope, productivity and quality from our understanding of the scientific principles governing mechanical devices (just as an example, the first weaving machine, a catalyst of the textile industry, was created in 1804 by Joseph Marie Jacquard).

Having an historical perspective we can analyze the conceptual framework which has been at the core of the development of classical mechanics (as the main part of physics for around a century). If we had to identify the main assumptions in that framework, there would be a large consensus on the following ones:

- Dualism and objectivity: mind and matter are separate, and the mind can be an objective, external observer of reality;

- Rationalism: the conscious processes we label as "reason" are (or should be) the main source of knowledge and justification in our analyses and actions; this is often put in contrast with our "emotions", who are supposed to be part of a different domain and mislead us in our thinking;

- Separation of scales and contexts: reality can be observed at different scales (in space and time) and in different contexts, and separating them facilitates our analyses without significant loss of capacity to explain the observed phenomena;

- Reductionism: reality can be decomposed into smaller constituents, and the behaviour of the whole can be deduced from the analysis of the parts, while their connections and interdependencies generally play a secondary role; also, models can be used to represent reality and they often become the object of our analysis as if they were the reality they represent (see A2.2);

- Linearity: as a valid approximation, changes in outcomes are proportional to changes in inputs; more generally, effects follow causes and we can effectively translate our intentions for change into linear planning, through which a conscious sequence of actions can lead us from present state A to the desired state B;

- Static equilibrium: we tend to give supremacy to the concept of equilibrium, as an object of analysis and as a state to which we aspire, and leave aside the relevance of pathway-dependent, dynamic evolutions;

- Determinism: through our objective access to reality we can identify regularities strong enough to operate as "laws" of nature and determine the future behaviour of observed phenomena; with enough information the future can become predictable, at least in statistical terms.

All these assumptions look sensible, even if some of them are very bold (in particular the assumption of determinism). Moreover, their value has been asserted over time by both the theoretical and practical developments derived from them. But at the same time the limits of validity of this coherent paradigm of thinking have been explored as well. In its leading role as the most successful scientific discipline, physics has since long entered into a dynamic process of creation of new paradigms of knowledge, every time the incumbent one proved to be unable to explain observed phenomena [Fiorini 2018]. Nowadays the universality of all the assumptions listed above is questioned by specialists in epistemology who ground their observations on the inadequacy of using mechanicism to analyze complex phenomena present everywhere. We know that "objectivity" cannot be taken for granted and that observing the observer is mandatory in the exercise of connecting reality to representations. Though, surprisingly enough, the paradigm of classical mechanics as described is still very much used in ordinary but not less complex matters and in particular in disciplines related to the behaviours of individuals and societies. The paradigm of classical mechanics has been and still is at the center of our frameworks of interpretation, at least in the Western cultures who have largely shaped the globalized humanity we live in. But this does not mean that it is the appropriate framework to deal with the challenges humanity faces now, as discussed in different sections below.

A2.2. REDUCTIONISM AND HOLISM

At the more general level, reductionism is the idea that applying a procedure of reduction to the object of our analysis increases our effectiveness in the process of understanding that object. In this sense it is impossible for humans not to be reductionist: from what was discussed in A1.3, our conscious access to reality happens through several operations of reduction. We cannot perceive the aspects of reality to which our channels of perception are not sensitive (although we have worked to overcome this with new artifacts such as the microscope and the telescope) and only part of our perceptions get to our conscious mind (although we are consciously aware of this limitation).

Moreover, we have issues when consciously dealing with intricate relationships and causality chains, starting with the fact that we only perceive the geometry of reality in 3 dimensions. Then it cannot be a surprise if in science and other domains, for the higher purpose of a better understanding, we try to explicitly apply reduction. It is very difficult for us to separate explanation from reduction. And we use several kinds of reductionist procedures. One is the idea (usually implicit) that models can be used to represent reality (as a map represents a territory) and so they become the object of our analysis as if they were the reality they represent. A second one, quite generalized in scientific disciplines, is that (as said in A2.1) reality can be decomposed into smaller constituents, and the behaviour of the whole can be deduced from the analysis of the parts, while their connections and interdependencies generally play a secondary role. Based on these two ideas, reductionist thinking and methods have been foundational of many (if not all) of the areas of modern science. Classical mechanics is a case in point, but not the only one: statistical physics is used to reconciliate the laws of thermodynamics with the explanation of macroscopic properties in terms of microscopic components.

The practical effectiveness of explanations obtained through reductionist methods is considered as an argument good enough to validate the methods, and this is usually an invitation to generalize them. If in some cases larger scales can be explained by what happens at smaller scales, we could extrapolate to say that certain areas of science could be based on other areas studying smaller spatial scales or organizational units. E.g. it is commonly accepted that the foundations of chemistry are based on physics and molecular biology is based on chemistry. A drift happens though when this is generalized to all disciplines and the relationship between them, up to the creation of a linear hierarchy of scientific areas, one starting with particle physics and going to solid state physics, chemistry, molecular biology, cellular biology, physiology, psychology and ultimately up to social sciences. Embedded in this hierarchy is the idea that the elementary entities of each discipline obey the principles of the discipline preceding it in the hierarchy. But not only that: this reflects the idea that reality itself can be described in terms of hierarchical levels (from elementary particles to atoms to cells to individuals to societies). Such a hierarchy does not necessarily reduce the importance of each discipline, it does not imply that each scientific level is just an applied version of the one preceding it (i.e. psychology is not applied biology or biology applied chemistry). But it can be a constraining framework, especially because it conditions the way we think about the relationship between different scales and levels: is society just a collection of individuals? Is sociology a consequence of psychology? The existence of different levels does not imply the existence of a simple hierarchy between them. Also, a hierarchical relationship between disciplines hinders the possibility of inter- and transdiscipinarity.

Another, more subtle way of reductionism is to believe that we will be able to explain and understand whatever phenomena beyond our knowledge by applying the same kind of epistemological tools we have been using until now, and in particular reductionism itself. This idea is not only reductionist (all aspects of reality can be reduced to what we can consciously understand today), it is quite arrogant. In this sense our capacity to build computing machines plays a fundamental role, because it brings the belief that whenever our mind is limited to handle the high dimensionality of a phenomenon, we can use computing to "manage" it and extract useful knowledge. This is in particular the expectation we have about modern artificial intelligence (AI) in its use of machine learning: the promise is that any phenomenon could be understood provided we get enough data, because we have computing techniques to identify regularities (patterns) in the data as a first step to find explanations of past behaviors and even predict future ones. But, whatever the additional and useful knowledge it can bring, AI is not breaking with reductionism since handling more dimensions does not necessarily lead to overcome the mechanistic approach (see A6.3.5).

The limitations of the effectiveness of reductionism appear with clarity whenever complexity manifests itself, especially in the form of emergent properties of a whole which are not deducible from the properties of the parts. Even if adhering to reductionism in the sense that *"the workings of our minds and bodies, and of all the animate and inanimate matter (....) are assumed to be controlled by the* *same set of fundamental laws"*, one can conclude that *"the ability to reduce everything to simple fundamental laws does not imply the ability to start from those laws and reconstruct the universe"* [Anderson 1972]. Which clearly states that the "fundamental laws" (and there are not so many of them) do not tell the whole story. Most natural and human systems are actually complex (see A5.1), they are made of large assemblies of autonomous parts (cells, living beings, organizations, societies, and so on) interacting between each other often in nonlinear ways and through multiple levels of feedback loops. For such systems reductionism to the behavior of the parts or to disciplines dealing with smaller scales or to fundamental laws is not enough. Whenever reductionism does not work, determinism (see A2.1) is also left behind. This is the case when a system is close to a critical point and infinitesimal fluctuations decide which branch of a bifurcation is taken: this is called "symmetry breaking" and it creates history (or "path dependency"). The future of that system cannot be anymore fully determined, it will be contingent upon unpredictable events.

While complexity is a strong argument against the universal validity of our reductionist assumptions, the debate is ongoing whether it is just an obstacle to be overcome by the next generation of reductionist tools or if the limitation is more substantial and the reductionist approach itself limits our capacity to grasp complexity. "Hierarchical reductionism" is a proposal to state that complex systems can be described as hierarchies of organizational levels, each of which only dependent on objects of a lower level in the hierarchy. But many thinkers observe that in complex systems larger scales of organization can influence smaller ones and feedback loops can create structures at a given level, independently of lower levels [Ulanowicz 1997].

Not the least, a strong school of thought advocates that complex systems (and the uncertainty to which they are associated) are inherently irreducible and that "holism" is required to deal with them. The term was coined in 1926 by Jan Smuts (military leader, statesman and philosopher) to designate the *"fundamental factor operative towards the creation of wholes in the universe"*. Holism or holistic science is an approach which focuses on the study of complex systems as wholes. Although it can be seen as a perspective complementary to reductionism, it is mainly driven by the exploration of its limitations. In this sense it connects and is fed by the work of many scientists exploring what lies beyond current scientific paradigms, whether looking at the realm of "post-normal science" [Funtowicz & Ravetz 1993] or "the end of certainty" [Prigogine & Stengers 1997].

The relevance of holistic thinking is growing inasmuch the consequences of our lack of understanding of complexity are becoming more evident. The awareness is now with us that science and technology, as practiced in the last three centuries, can be at the same time an extraordinary factor of progress for humanity and an accelerator of processes leading to self-destruction at a global scale (through climate warming, loss of biodiversity, exhaustion of non-renewable resources, and so on). How could that be? Our epistemological blind spots are a good candidate for the explanation. When burning fossil fuels pollution is so evident that by paying attention we could have easily imagined negative consequences at scale. But the lack of a systemic, holistic framework made us (consciously or not) blind to the magnitude of the long-term consequences, until they manifested themselves (and even now, denial of the implications is quite widespread). From a reductionist perspective and even within a precautionary framework, it made sense not to look at the potential feedback loops. From a holistic perspective, the question on unintended consequences is mandatory.

A2.3. SYSTEMS THINKING

Systems thinking is the most general kind of answer to the limitations of reductionism. The approach builds upon the consideration that reality is systemic, it is a system populated by systems. What makes something a "system"? Its characterization as a coherent set of interrelated and interdependent parts. The system would not exist without the parts but it would not be either without the relationships between the parts giving to it an overall coherence, which we can observe as a distinct identity (distinguishing the system from its environment) and many times as a specific way of being in the environment. From this general definition it is difficult to find anything which is not a system. But for the analysis of very simple systems (a ball, a chair,...) the systemic perspective is not particularly fruitful: mechanicism deals with these better than systems thinking. On the contrary, as discussed in A2.2, for the analysis of complex systems mechanicism and reductionism are insufficient, or even inappropriate.

The abstraction we use when talking about a "system" as a "whole" and its "parts" is extremely powerful as a tool for analogy which can be applied to whatever domain, human or non-human. This is why the history of systems thinking is so rich in parallel developments in many different disciplines. Relevant contributors to the field come from physics and chemistry (Ilya Prigogine, Fritjof Capra) biology and ecology (Ludwig von Bertalanffy, Humberto Maturana, Francisco Varela, Howard T. and Eugene Odum), sociology and political science (Edgar Morin, Immanuel Wallerstein, Niklas Luhmann, Talcot Parsons), psychology, psychiatry and education (Ross Ashby, Anatol Rapoport, Alfonso Montuori, economics and management (Kenneth Boulding, Peter Senge), and so on.

As mentioned in the Introduction, systems thinking is a rare but very positive case in the history of science in terms of gender balance: contributions to the field by women have been significant from the very beginning and largely shaped the evolution of knowledge and agendas of research. Ada Lovelace, at the onset in the 1830s of what later became computer science, is a case in point. In the 20^{th} century and more recent times, coming from many different backgrounds Donella Meadows, Margaret Mead, Mary Catherine and Nora Bateson, Elinor Ostrom, Isabelle Stengers, Olivia Bina, Rika Preiser, Maja Göpel, Mariana Mazzucato, Petra Künkel, Lene Rachel Andersen, Nicole Dewandre, Anne Snick, among many others, have produced relevant contributions to the large domain of systems thinking and complexity theory.

Over time systems thinking has become a domain of study by itself, with the peculiarity of being truly transdisciplinary. Many of the most relevant contributors (such as Gregory Bateson and Ervin László) have crossed many disciplinary boundaries to produce some of the most original ideas for the systemic approach. Others, such as Ludwing von Bertalanffy and the linguist Béla Bánáthy, have oriented their investigations towards the development of a general theory of systems, valid for all instances of the concept in all fields of science and human activity. That aim is framed by the observation that:

> *"there exist models, principles, and laws that apply to generalized systems or their subclasses, irrespective of their particular kind, the nature of their component elements, and the relationships or "forces" between them. It seems legitimate to ask for a theory, not of systems*

> *of a more or less special kind, but of universal principles applying to systems in general."* [Bertalanffy 1968]

While the attempts by Bertalanffy and others to elaborate a General Systems Theory have certainly brought light to the field, it is still unclear if the aim will be fully completed. Commonalities among systems are important: they are defined by boundaries, they have internal structures, they depend on their environment and their internal configuration and interdependencies between parts, they exhibit specific behaviors which can be synergic or emergent (the whole being more than the sum of the parts), and in the case of living beings they can develop intentional actions and purpose. Some behaviors are particularly relevant and widespread if one looks at manifestations of life with a systemic lens:

- Persistence: systems tend to self-perpetuation;

- Adaptation: systems tend to adapt to the variations in their environment, by performing the internal changes required to keep the integrity of overall functions and purpose;

- Homeostasis and resilience: systems tend to recover from external disruptions and maintain their key characteristics;

- Feedback loops: systems are able to create new behaviors with the overall effect of counteracting perturbations and keeping a stable operation;

- Learning and shifting: systems are able to transform their behaviors and operate in different dynamical regimes in response to significant changes in their environment.

In spite of the commonalities and especially when considering complex systems (see Section A5), the object of analysis is so reluctant to the traditional approach of science (looking for universal laws and determination) that rather than the foundation of a general theory we have for the moment a toolbox for multiple descriptions of complexity.

A2.4. PROCESSES. PROCESS PHILOSOPHY

A crucial aspect of our understanding of reality is the appreciation of time, and if it plays the role of a fundamentally independent dimension or not. In other words, if the arrow of time is real or not. We all know that things change with time but when considering the existence of universal laws we take for granted that they are valid not only for all spaces but also for all times. And if we assume that a set of fundamental laws exists from which everything is derived, the relevance of time is no longer the same: if we were able to know all those laws, with sufficiently precise information about initial conditions the state of the universe (or any system under analysis) could be determined at whatever moment in the future. In that scheme time is just a control variable, the cursor whose position determines at which point of the movie we are, but the movie is always the same. In other words, if destiny exists, time does not have a relevance of its own. And similarly with human agency (see A3.2). The consideration of time is an essential aspect of epistemology, and of philosophy at large. While classical mechanics is characterized by the belief in the existence of enough universal laws to predict the future and hence questions the relevance of time, process philosophy is exactly the opposite in this respect. A process is a set of activities realized by interacting elements which produce a change (e.g. the process of digestion of food by our body): the dynamic character and the dependency on time are built in the concept. Process philosophy identifies reality with change.

This is not the perspective adopted by all thinkers. Starting with Plato, Aristotle and Parmenides in classical times, many philosophers posit that true reality is timeless, based on permanent substances, to which processes are subordinated. Change is accidental wheras substance is essential, and this applies in particular to human identity. This consideration is very close to the separation of ontology, epistemology and ethics (see figure A4 in A1.2). If reality is essentially timeless, ontology (what is) is mapping a fixed territory and then science can engage in its exploration and produce timeless knowledge. The exploration may be difficult but is oriented towards a fixed destination and progress of knowledge can be achieved. An alternative tradition of thinking is focused on change as the substance of reality: "being" actually means "becoming" [Prigogine 1980]. With Heraclitus as its main representative in classical times, this philosophical tradition has been equally rich, especially since late 19th century: from many different perspectives, Hegel, Marx, Nietzsche, Bergson, Heidegger, Sanders Peirce, Whitehead, Smuts, Korzybski, Mangabeira Unger, Derrida, Latour, Deleuze, Prigogine, Stengers are among its proponents.

Process philosophy considers that, to the best of our conscious elaboration, reality is the joint outcome of countless processes taking place in parallel over time in specific places and contexts and producing structures in permanent evolution and interaction. Structures are configurations reflecting the state of play of processes at a certain moment. Processes are permanently exchanging energy, resources and information with their environment, created by other processes. There is nothing purely static in them and their persistence depends on their adaptation to context. In other words:

> *"In a concise way, this new understanding may be characterized as* process-oriented*, in contrast to the emphasis on "solid" system components and structures composed of them. These two perspectives are in their consequences asymmetrical: whereas a given spatial structure, such as a machine, determines to a large extent the processes which it can accommodate, the interplay of processes may lead to the open evolution of structures. Emphasis is then on the* becoming *- and even the being appears in dynamic systems as an aspect of becoming."* [Jantsch 1980]

Processes are not manifestations of a larger and coherent whole, they are autonomous and engaged in the pursuit of persistence. This also means that they can be in conflict with each other, although collaboration, concatenation and intertwining of processes are much more often observed in nature than competition [Gorissen 2020]. Also, from the conjunction of processes self-organized patterns can emerge (see A5.3). And this perspective is aware of the existence of different scales and levels of processes, organized in some kind of hierarchical manner. Processes can have sub-processes and so on, although relations between different levels may not be as simple as implied in the reductionist perspective and the meaning of "hierarchy" may be ambiguous (see A6.3.1). Last but not least, an epistemology dealing with complex systems cannot take change as incidental but as substantial. Complexity thinking is to a large extent built upon process philosophy (see A5.1).

A2.5. CYBERNETICS

We conclude this non-exhaustive review of different models of thinking with a discipline focusing on interactions, communication and control. The word "cybernetics" is not itself a neologism, it was used in ancient Greece to express the "governance" of people. Physicist André-Marie Ampère used it in 1834 to denote the sciences of government in his classification of human knowledge. And in 1948 Norbert Wiener started its modern popularization by defining it as *"the scientific study of control and communication in the animal and the machine".* Nowadays, as the word "cyber-space" suggests, it is frequently associated to computer science, to which emergence it definitely contributed. But from the point of view of epistemology the importance of cybernetics is associated to the shift it brings by subverting previous conceptions of causality and determination. In a behavioral approach there is a linear sequence between cause and effect, and hence a linear conception from purpose to effect, as shown in figure A8:

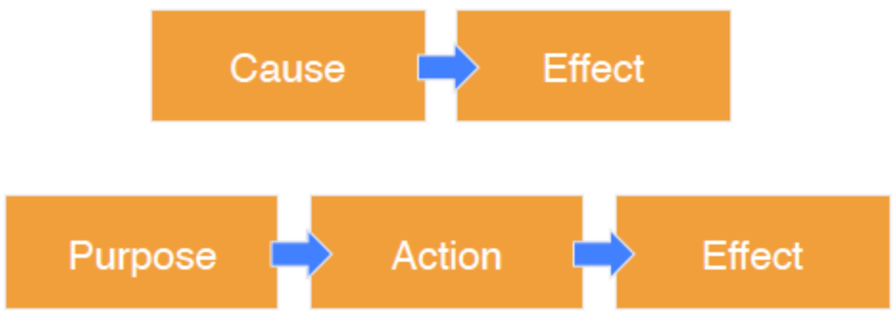

Figure A8. Linear sequences of cause and effect (source: own elaboration)

This is not incorrect in itself but at least incomplete. First, this conception presupposes that we can observe from the outside both the cause and the effect and then define as external observer what is the appropriate action corresponding to our purpose (see A1.4). Second, it ignores potential reactions and feedbacks due to the effect. Which may be reasonable for a large number of cases but not all. To make clear the difference, Gregory Bateson famously used the mental experiment of kicking a ball versus kicking a dog. The ball by itself will not produce any relevant reaction or feedback and taking into account the direction, intensity and point of impact of the kick, its trajectory can be predicted with precision. Kicking a dog is a completely different matter: we cannot even know if she will run away, attack us in response or go around wondering why she has been kicked. The cause-effect epistemology is not anymore of much use when dealing with living beings.

When the scientific field of cybernetics emerged in the 1940s it was inspired by the use of a "governor", a centrifugal feedback valve used by James Watt at the end of 18th century for controlling speed in his steam engine. This had been already mentioned by Alfred Russel Wallace in his essay on biological evolution in 1858, as a metaphor to describe the capacity of the "struggle for existence" to discard failed experiments [Bateson 1968]. The existence of feedback loops is a major aspect of cybernetics: the possibility to design them in order to provide stability to engineered systems (see figure A9) has been a purposeful focus of the discipline since its inception. But the consideration of feedback loops has had wider implications: first, it outlined the relevance of interactions between parts of a system as well as of the information carried along by those interactions. Hence it emphasized as well the role of communication and its substantial role in conditioning the behavior and stability of systems.

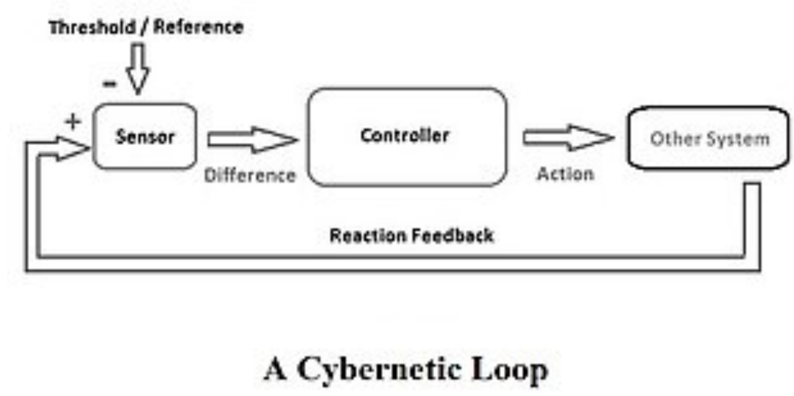

Figure A9. Scheme of a basic feedback loop (source: Wikipedia)

Over the last decades cybernetics has developed into an extremely rich field of activity, producing new concepts and enriching other disciplines, particularly biology. While the study and design of feedback loops acting directly upon the system object of analysis is now labelled as "first-order cybernetics", new branches emerged, referred as cybernetics of second or higher orders (see A6.2).

Cybernetics also contributed to the development of complexity thinking (see Section A5). By emphasizing that the overall behavior of a system depends on the interactions between its parts it opened the door to the conceptualization of complexity. And, at least for those willing to pay attention, it outlined that all living systems are complex, full of interactions and feedback loops, sometimes extremely intricate. Moreover, it led to the evidence that the relationship with a complex system (e.g. any kind of living being) is unable to follow the simple cause-effect scheme, it resembles more to an endless cycle of questions and responses, as depicted in figure A10.

Figure A10. Dealing with complex systems (source: own elaboration)

A3. INNOVATION AND BEYOND

A3.1. R&I PROCESSES. INNOVATION THEORY

The continuous creation of new technology is an activity as old as humanity itself, but in 20th century it acquired a new dimension when transformed into a systematic process largely derived from and coupled with scientific discoveries. The intertwined process of science, innovation and technology has now become a major factor of evolution of human societies. This outcome was shaped by historical contingencies, with an inflection point happening in the wake of World War II, when the USA conceptualized and institutionalized the role played by science and technology in modern societies [Bush 1945]. This happened after a period of 30 years marked by two global conflicts whose fate was determined to a large extent by science and technological developments, as had happened as well in many previous conflicts in the history of humankind. This led naturally to the idea that the country mastering the further development of science and technology would be in a much better position than any other to look at the future with confidence. The report by Vannevar Bush and other coincident events were influential in shaping how R&I was conceived and developed in a systematic manner in the currently most powerful country on Earth. This path was replicated in the following decades by most industrialized countries. This conceptualization included a number of ideas later put in practice and still relevant to this day:

- Research and innovation are major expressions of human genius and the foundation for progress of societies, and as such their development should be promoted;

- R&I not only bring better responses to human needs but also protection from a variety of threats and, generate economic growth and prosperity;

- With these arguments in hand, it makes sense for governments to invest massively in R&I;

- The concrete and most effective way to foster R&I is through the existence of different kinds of institutions playing different roles in an arrangement of processes leading from fundamental research to practical applications;

- A requirement for such specialized institutions to be effective is to selectively enroll the most capable people and ensure excellence through competition, collaboration and emulation among the community of scientists and innovators.

The Bush report led, among other things, to the creation of the National Science Foundation (NSF) and the National Institutes of Health (NIH) in the USA, as key instruments to orient, fund and develop scientific research for the accelerated development of technology. Different roles are also played by higher education, R&I funding agencies, public and private research institutes and private corporations ensuring the commercialization and wide-scale exploitation of innovative products and services.

In this conceptualization, science and technology are consciously considered as processes happening outside society, in specialized institutions where the most brilliant minds work for the advancement of humanity and to produce new discoveries and their practical derivations, as well as the responses to new challenges and needs. This framing of separation is consistent with the way mainstream economic theories take into account the role played by the unpredictable developments of R&I. They are deemed exogenous factors, shaping the boundary conditions under which economic agents operate but doing so from outside the economy. This is an epistemological paradox: the most important factor for the advancement of productivity and human wellbeing in a modern economy is considered as a "deus ex machina" bringing an ongoing flow of innovations to the economic processes. Mainstream economics generally suspects any kind of public intervention in the economy, but this very special status of R&I justifies massive public investments to keep the machine of inventions going, as the driver of a positive evolution of human societies.

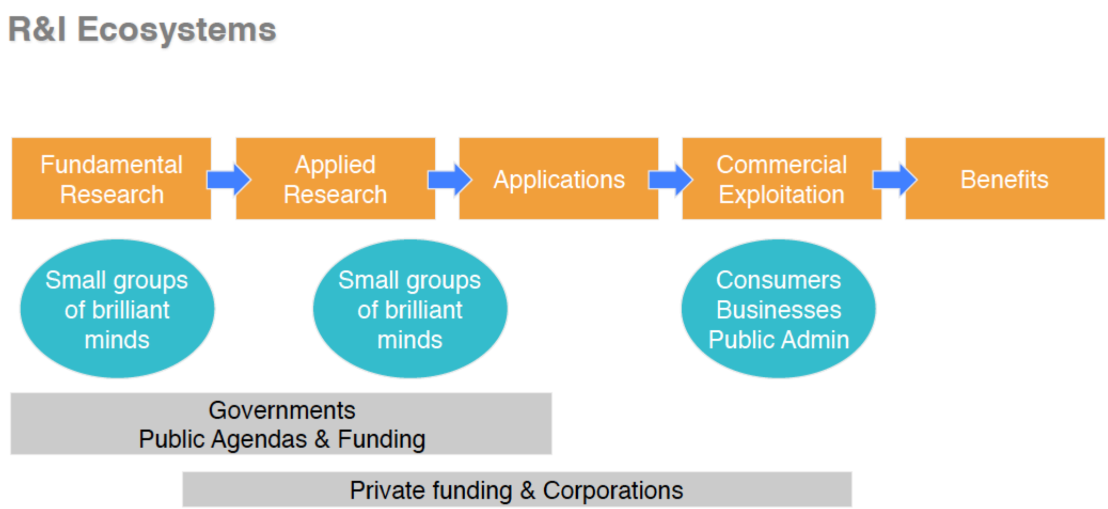

Figure A11. Conceptualization of Research & Innovation processes (source: own elaboration)

As depicted in figure A11, in these arrangements of R&I processes two interfaces connect them to society. Upstream, funding comes first and foremost from governments, especially due to the strategic role of technology in geopolitical and security terms. Funding is provided to develop certain activities and not others, based on priorities in the strategic agendas governing scientific research and technological innovation. Most of the funding and the decsions on priorities come from governments, among other reasons due to the key role of science and technology in geopolitical and security issues. However, governments are not the only players and do not take their decisions in an isolated way: private sources of funding, high-tech industries and the communities of scientists and innovators play their role in shaping the decisions and their consequences.

Downstream, the ultimate test of technological innovation is left to the markets - the pertinence of a particular development is validated by the financial profitability of the investment. Actually, the pathways from applied research to applications and from these to commercial exploitation are poorly represented by straight lines. Many unexpected things can happen in the intermediate processes and conversely many expected things may not take place. Nevertheless, the straight lines represent the linearity of deliberate purposes: both innovators at the individual level and start-ups and corporations at the organizational level intend to bring their innovations to commercial exploitation, since this is seen as the realization that those ideas were appropriate, timely and well implemented. While this idea continues to be generally accepted, the validation based on market results has evolved in recent decades.

During the industrial era the transformative impact of technological innovation was materialized through large investments over long cycles and measured through companies´ operational indicators (number of units sold, number of employees, revenues, profits, etc). Nowadays the dynamic is different, as part of the general process of financialization of the economy. Value maximization of innovative companies in stock markets derives from expectations on who will conquer in the shortest time a de facto monopoly in its particular niche. Unprofitable businesses can be highly valued if expectations about their future are positive. This dynamic is especially intense in the domain of digital technologies, now almost universally considered as the paramount example of innovation, where network externalities (aka "the Metcalfe´s law") are strong enough that the logic of "the winner takes all" becomes valid in each niche (as has happened with a number of digital giants, such as Microsoft, Google, Amazon or Facebook). It is questionable, though, if this is not leading to an innovation paradox. Expectations about which player will dominate each market segment in the future create high volatility in the present and exclude a high percentage of innovations from completing their cycles. Financial speculation works in favour of the rapid creation of monopolies, not necessarily the best landscape in terms of innovation and transformative responses to societal needs.

The expression "R&I ecosystem" is now used frequently. It is an imported metaphor coming from the literature of business management and strategy since the word "ecosystem", coming from biology with a specific meaning (see A4.2), does not apply literally. The purpose of the metaphor is to outline the dynamic relationships between the organizations and individuals involved in Research and Innovation activities and how they impact on society. A sketch such as figure A12 is a more faithful representation of the webs of interactions between actors of R&I processes. Real processes, and in particular the connection between fundamental and applied research, do not happen in completely linear ways. As an example, most of technologies relevant for digitalization are consequences of the advances in philosophy and mathematics in 18th and 19th centuries and in fundamental physics in the first decades of 20th century, and in that domain the sequence of connections leading from science to technology have not been straightforward. The connection generally happens through cyclical waves (aka as "industrial revolutions") and there can be scientific breakthroughs without applications in the practical domain for a long time, as well as a lot of applied research and applications derived from the evolution of previous applications rather than from breakthroughs in science. More generally, a broader set of actors is of relevance and complex patterns of interactions between them are established, somehow as in a biological ecosystem.

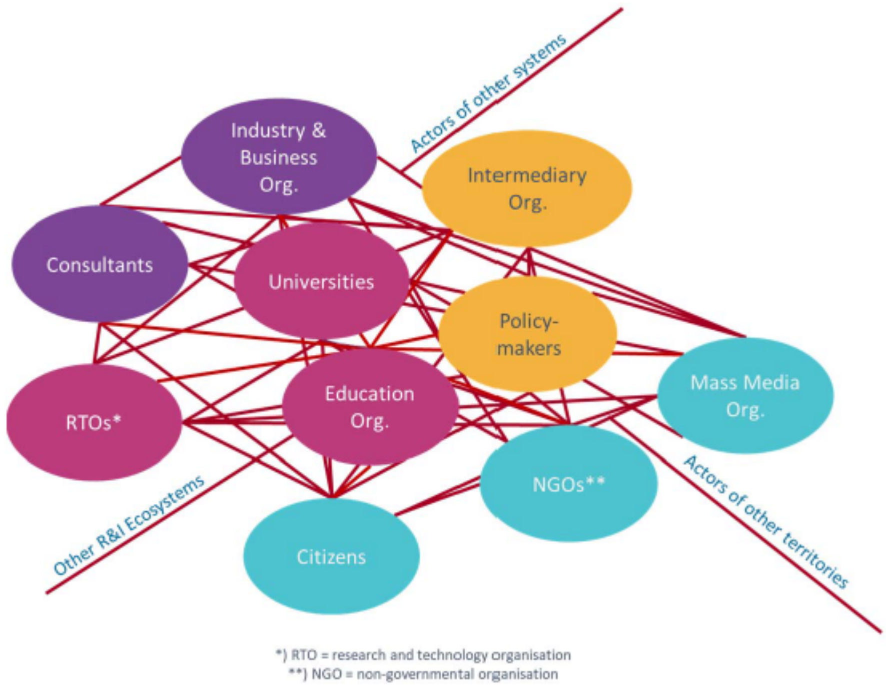

Figure A12. Broader network of actors in R&I processes (source: AIT)

That said, this complexity does not break substantially with the arrangements established after World War II which, in our view, is still framing the main R&I ecosystems in most countries. Such arrangements have been extremely successful in their expansion and impact in the last 70 years. This does not mean that R&I, as they exist today, are in all details the outcome of the execution of a well designed plan: in their development there has been a lot of place for creativity, improvisation and entrepreneuship. Discoveries have been genuine, and in many cases completely unexpected. Out of some of these entirely new sectors of activity have emerged, the most obvious example being the digital sector. The overall success was actually expected to happen out of the systematization and exploitation of scientific inquiry and technological development. But many of the concrete characteristics and details of actual configurations could not be anticipated. In a way this already shows that processes of R&I initiated long ago have been creating "ecosystems" through the interactions between many different actors at local, national and international levels. Competition has been part of the game but collaboration in the context of the overall framing has been more relevant to drive the co-evolution and growth of what we can now label as "R&I ecosystems". And it is pretty obvious that the outcomes of R&I derive from non trivial interactions between autonomous actors in many different contexts and levels. As will be developed in Section A5, this is a good argument to adopt a perspective from complexity theory in order to understand better not only the evolution of the R&I ecosystems as they are but especially what kind of additional layers of contextualization and interactions are needed to ensure that the framing of Responsible Research & Innovation (RRI) pervades the whole sphere of R&I. RRI is important for the future because, for all the virtues and benefits coming from R&I activities, society has become increasingly aware of their "collateral effects" or "negative externalities" (as they are still usually framed, see figure A13).

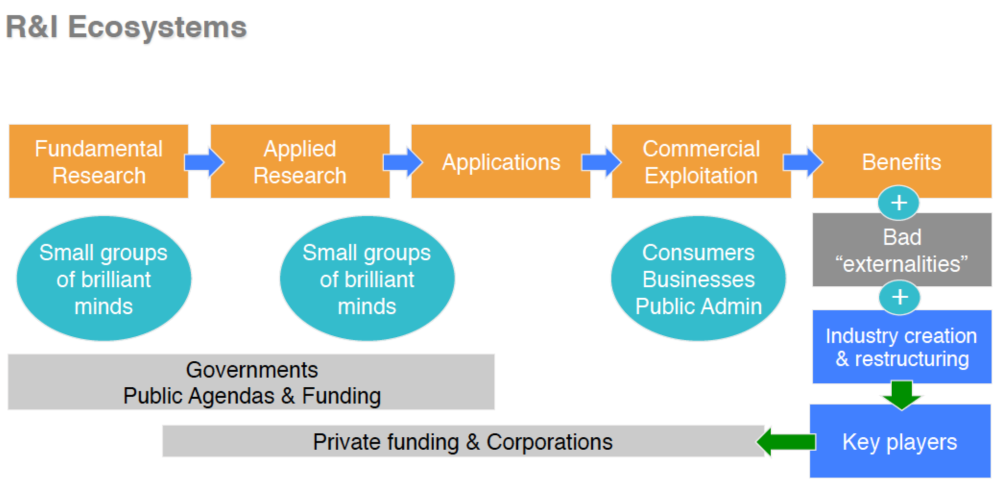

Figure A13. Conceptualization of Research & Innovation processes (source: own elaboration)

The effectiveness of our technological developments not only includes the possibility of mutually assured anihilation through a vast arsenal of weapons of mass destruction. We also face the very real threat of self-inflicted collapse, catastrophes and perhaps human extinction, as a consequence of our indiscriminate use of certain technologies to promote material development. The use of fossil fuels as a dominant source of energy is a fundamental component without which rapid industrialization and globalization would not have happened, or at least not in the way we know them. This leads us into considering that the purposeful development and use of technology produces unexpected, and not always positive feedback. Climate warming or the widespread pollution by plastics are just two examples of this, of such an overwhelming size that it is quite strange to label them as "collateral".

As a result of the dynamics of R&I processes and with a special momentum since massive digitalization started more than 30 years ago, whole industries are being created or restructured, leading to the emergence of new private players which often succeed in establishing themselves as monopolies in their domains of operations (think of the GAFA companies - Google, Amazon, Facebook, Apple - in the digital arena). We are submerged by a constant deluge of new artifacts and techniques being deployed, which speak for an ever accelerating advancement of humanity, while at the same time we face powerful trends destabilizing our environment and social arrangements. Technology is part of those trends, notably Artificial Intelligence (AI) and robotization as vehicles to replace jobs performed today by humans, in the name of efficiency. We need to consider whether the future will be techno-utopian or technolitarian, driven by the adoption of new technologies without regard to their social and environmental consequences. The dominant discourse about technology defends its neutrality: it is up to humans to take the best decisions regarding the exploitation of technology and mitigation of its potential pitfalls. The processes of science and technology could be framed in different ways. We recall the expectations of times when the Internet was starting its explosive path, to bring the benefits of individual empowerment, quick and universal diffusion of knowledge and the emergence of new forms of collective intelligence. The comparison with what actually happened is not an exercise of pure congratulation: those expectations were surely met, but in the world of pervasive digital platforms we now observe the phenomena of manipulation, loss of privacy and autonomy, and exponential growth in wealth inequalities [Zuboff 2019].

Even before the current alarms bells on climate change or the dangers of widespread digitalization had risen to the top of public agendas, many thinkers started reflecting on the role of technology in society from a philosophical perspective. Amongst others, Martin Heidegger, Jacques Ellul, Marshall McLuhan, Gregory Bateson and his daughters Mary Catherine and Nora, Gilbert Simondon, Isabelle Stengers, Bruno Latour, Robin Mansell, Nicole Dewandre and Luciano Floridi, have elaborated on the topic. Notwithstanding their efforts, the complex entanglements between technology and social and cultural transformations lie in a domain yet to be fully explored beyond our current practices and comprehension. A huge gap persists between the philosophy we still use today to discuss technology and the progress in thinking we would need, in order to make the most out of our technical achievements. Filling the gap requires combining many different levels of abstraction and cannot be separated from a more general questioning of our epistemological frameworks (see A1.1 and A1.2). The gap between the promises of technology and the real state of affairs in which we live, is directly connected to the stickiness of outdated frameworks of interpretation through which we deliberately ignore the "collateral" consequences. We need to question how we make sense of the world around us. Due to the importance of both technology and the challenges that humanity faces today, this is not a minor issue, nor an academic one. At this stage of the history of humanity, there may be nothing more important and practical than changing the way we think about ourselves and our relationship to the world, and hence about technology.

Scenarios anticipated 50 years ago by the Club of Rome and leading to the collapse of human civilizations in spite (or because) of their high degree of technological sophistication [Meadows et al 1972] have been until now confirmed by the actual pathway humanity followed since then [Turner 2014, Weizsäcker et al 2018]. In our view the negative outcomes are not collateral, they are emergent properties of our complex R&I ecosystems. This indicates that there are missing elements in current R&I configurations:

- R&I processes should address our societal challenges. In 2020, it is clear that the current processes do not deal properly with the self-inflicted existential threats to the sustainability of human societies. The process of elaboration of R&I agendas should integrate the most relevant challenges, ameliorating the products of previous R&I successes, taking care of the so-called "externalities" and including civil society and citizens as such (not as consumers) in the overall process of R&I.

- Given the extraordinary momentum of technological innovation (especially in areas such as digitalization and AI), it is not reasonable to expect that momentum to be spontaneously aligned with the official consensus on societal challenges (such as the declaration of the Sustainable Development Goals and the Agenda 2030 [UN 2015]). This alignment must be actively promoted. That momentum has its own dynamic and autonomy, largely independent from the pressing issues we face [Alvarez-Pereira 2019]. R&I ecosystems should produce solutions to our problems today and work towards solving and anticipating the problems of tomorrow.

In conclusion:
- The existing arrangements of R&I processes in modern societies include and are the product of a large number of interactions and interdependencies between autonomous actors of different kinds and of different perspectives, cultures and interests;

- R&I processes are not able to respond by themselves to growing challenges deemed until now as "collateral effects" or "externalities" but with a high potential of disrupting human societies in a negative direction (such as climate warming, biodiversity loss, inequality growth, and so on);

- This imbalance justifies deploying RRI policies not only as "nice to have" but as a fundamental lever to reframe R&I ecosystems away from the currently projected pathway to collapse.

A3.2. PARADOX OF AGENCY. THEORIES OF CHANGE

In the perspective of innovation certain people have a specific capacity to identify features of life in society as "problems" or unmet "needs" or "opportunities", and to propose innovative "solutions" to address them, which may be socially validated, depending on their degree of accceptance by their users and consumers. This perspective is the realization of the concept of agency, the capacity of humans to make choices and act consciously and purposefully to change aspects of their environment (social or natural). The most publicized examples of innovation, and singularly those of the digital domain, emphasize the capacities of some outstanding individuals, e.g. Bill Gates, Steve Jobs, Jeff Bezos or Mark Zuckerberg, and the ways in which they have "changed the world". This framing is a powerful incentive for individuals of next generations to invest themselsves as researchers, innovators and entrepreneurs. It is well known that very few will succeed, but the prize is too attractive to ignore: it includes both financial rewards and a feeling of satisfaction from an enduring impact on how the world works.

This framing can be considered as a side effect of the institutionalization of R&I activities. Research and innovation are deemed to happen in a small elite of global institutions. These are located in a few places (like Silicon Valley and Shenzhen for the digital domain) and nurtured by the outstanding individuals with skills in a restricted set of disciplines (e.g. science, technology, engineering and mathematics). Competitiveness is the dominant rule, among the brilliant minds and among the institutions, to occupy one of the few places at the leading edge of the process of transforming the world.

From the epistemological point of view, this framing is paradoxical. It is built upon the assumption that small groups of brilliant minds can be clever enough to understand how the world works and change it (or at least steward it) in a desirable direction. This is very close to the assumptions of mechanistic thinking (see A2.1), in particular dualism (we can observe from outside) and determinism (we can understand how a system works and evolves). It is interesting to notice that this consideration is actually consistent with what has happened in the last decades in terms of the accelerated growth of social inequalities and the concentration of wealth and power at the very top of the social pyramid. The message that society receives is that "innovation is unstoppable" and that we have to adapt to it, as if it was a natural phenomenon on which we have no influence, like the Sun rising and setting everyday. This, for the immense majority of people, is a denial of their human agency. It is the denial as well of the social nature of R&I processes (see A3.1).

Another aspect of the paradox is that, in principle, transformations of the kind produced in this way should not have negative consequences of relevance. This is why we label them as "collateral" or "negative externalities": we do not consider possible that the exercise of human agency at the highest level of excellence in scientific knowledge, technological acumen and management techniques can possibly produce negative results as a direct outcome. But this is what happens at scale, as a consequence of our blind spots on the nature of conscious purpose (see A1.4 and A1.5).

Taking into account the above, we reflect on how to create the changes in the world that we need to avoid high degrees of self-destruction. There is a substantial amount of literature about the topic in the domain of "Theories of Change". We will refer here to one particular synthesis in four types of scenarios for the governance of a holistic transition towards sustainability, as presented in table A2:

- The "fatalist" scenario is the one in which we live. To a large extent human systems are so stuck in their own logic of operation that we are not being able to create the required transformations at the appropriate pace (e.g. climate warming or Covid-19);

- The "individualist" scenario ("sustainability through the market") is the one which most governments believe in. It is based on a combination of appropriate regulations and market-driven innovation to do the job. But sustainability concerns are not new: the Club of Rome [Meadows et al 1972] celebrated its 50th birthday in 2018 and the concept of "sustainable development" is more than 30 years old [WCED 1987]. So, either we are not using the market tool for sustainability or it does not work well enough, or a combination of both;

- The "hierarchist" scenario (with a top-down central management of the transition) seems simply impossible, at least in most countries, China being the obvious exception. While cultural distance makes it difficult to believe that the Chinese way of crafting an "ecological civilization" could be exported to Western countries, it could become a model for many other countries, especially in Asia, if successful;

- The "egalitarian" scenario (with multi-actor and learning-by-doing processes) is the one with greater chances of sucess. However it requires an epistemological shift to understand how complex systems can change. This is the scenario that policies like RRI are promoting, especially when combined with the capacities of communities of actors at territorial levels, as in SeeRRI.

Fatalist	Hierarchist
'First, disaster must happen' -No governance; wait for events creating windows of opportunity -Actors in stalemate over means and ends	*'Let's put a man on the moon!'* -Top-down central management -Government has power or legitimacy; means and ends clear
Individualist	**Egalitarian**
'Sustainability through the Market' -Price and tax policy -Legitimacy for such policy; ends known; market can solve all remaining bottlenecks	*'A good transition arena will do it'* -Multi-actor Arena process; learning-by-doing action research -Means and ends to be clarified; no dominant actor; actors tend to agree on rough direction of change

Table A2. Modes of transition management [Tukker & Butter 2007]

A3.3. COMMUNITIES

Communities are important in the context of creating self-sustaining R&I ecosystems based on RRI. In conceptual frameworks of social sciences the defining elements are usually individuals and society at large. Innovation studies also consider the role of public policies and the involvement of individuals as crucial, mainly as consumers and sometimes as citizens. Besides society and individuals, only institutions and stakeholders representing certain types of activities (as those forming the quadruple helix) are considered. But communities are not really part of the discourse. When thinking about what shapes the beliefs and behaviours of individuals, as well as their relationships with their environment, communities are actually important. Communities are groups of individuals having something strong in common. Being part of a community is typically an all-engaging experience, which has the complexity of life: communities are not organized as bureaucratic organizations (governments as well as corporations) into ministries and departments, they function in ways dealing with the totality of reality. Think of a family as the smallest example of a community: different members have different roles and perspectives but the family is a whole with no purpose other than living together and ensuring the wellbeing of its members. Individuals do not belong to organizations in the same ways as they belong to families and communities. As an employee you are never fully engaged, only your professional skills are in a very specific context and for concrete purposes. And this rule is systematically enforced, so much so that an astonishing number of people in modern economies believe that their jobs are meaningless [Graeber 2018]. Being member of a community is not necessarily pleasant but the first element it provides is meaning.

This points to the central role of culture in communities. Not only in the sense that communities may be defined by a specific culture, like the worldwide community of performers of classical music or any religious community could be. It is also because what makes communities strong and the main element they share is of a cultural nature: it can be the culture of being a multicultural community, but it is beyond a narrow definition of what it is to be human. For most communities a defining element is the territory in which they live. At times of virtual space, bonds with physical places are still extremely strong, again because they are all-engaging: geography, language, history, traditions, local knowledge are not separate departments of a territorial community, they are all intertwined in a certain way of living, working, eating, moving, dreaming, loving in a place.

Since they are not purpose-driven organizations, it is quite natural for communities to take care, to provide for one another, especially in times when they are stressed for whatever reason. Wellbeing of members is the closest to an expression of purpose that a community could have, and it is well understood that it depends mainly on taking care of each other and taking care of the environment from which resources are obtained. In the history of humankind, the capacity of communities to organize themselves and take care of scarce resources is a more frequent case than the contrary. The belief in the "tragedy of the commons" is not completely devoid of rationale, but it would be a blind spot to ignore that commons can be properly and efficiently managed by communities without the intervention of centralized institutions or market actors [Ostrom 1990].

This is relevant when addressing how responsible innovation could work in territorial contexts, at the intersection of RRI and RIS3 policies. The way R&I processes are organized today (see A3.1), they ignore territorial communities. Most of these are located far away from the centers of the globalized R&I ecosystem, and their only option in dealing with R&I is basically to adopt whatever technologies and innovations have been created elsewhere, far from their particular and place-dependent challenges. This is why combining RRI with territorial considerations is so important, but it cannot be done at the expense of continuing to ignore the communities. Within the appropriate conceptual framework, such as the one developed by SeeRRI, the role of territorial communities can be enhanced in a way that they could effectively contribute to address, in their own autonomous ways, the challenges of sustainable wellbeing as they can be expressed in their geographical, cultural and historical contexts.

This approach is not without precedents, it is inspired by existing examples around the world, such as:

- the Regenerative Communities Network (RCN), an association coordinating and supporting 16 territorial communities around the world engaged in initiatives of regenerative and wellbeing economy;

- the Wellbeing Economy Alliance (WEAll), a collaborative network of 120+ organizations, alliances, movements and individuals working with communities all around the world and sharing the purpose of making real the wellbeing economy, one that delivers for humans and nature as well;

- the Apheleia association, a network of territories in Portugal, Italy, Brazil, Angola, Cap Verde and China, pursuing sustainable development through the valorization of culture and heritage [Apheleia].

A3.4. RRI PROCESS DIMENSIONS

RRI is a breakthrough in the framing of R&I processes in society. It is a fundamental piece of the Conceptual Framework of SeeRRI. This section does not elaborate further on those frameworks already elaborated by others for the conversion of RRI from a set of abstract concepts into practices implemented across all kinds of institutions involved in R&I activities. Those are already well documented. This section briefly sketches why the four process dimensions associated to RRI (Reflexivity, Inclusion, Responsiveness and Anticipation [Stilgoe 2013]) address a number of issues outlined in other sections of this report. Hence it shows the high degree of coincidence between the questions raised by the intellectual foundations of our approach and the definition of the RRI process dimensions as a *"framework for responsible innovation"*. The proper alignment of the SeeRRI Conceptual Framework with the RRI process dimensions is discussed in Section 2 of D4.1 and in particular in D2.2.5. All literal citations below come from [Stilgoe 2013].

Reflexivity is a requirement to address how our R&I processes are conceptually framed, in order to question the framing and identify what could be misleading or missing. It is directly related to the considerations on the existence of frameworks of interpretation conditioning the way we think and we translate perceptions into conscious reasoning (see A1.2 and A1.3). Reflexivity is a pre-requisite to identify and avoid our blind spots and the pitfalls of conscious purpose (see A1.4 and A1.5). Epistemological advances, such as those described in Section A2, are a consequence of reflexivity which is itself a characteristic of second-order cybernetics (see A6.2). Moreover, reflexivity scrutinizes *"the value systems and theories that shape science, innovation and their governance"*, a mandatory action if the consequences of present arrangements of R&I processes are to be addressed (see A3.1).

Inclusion addresses the need to include all types of stakeholders and society at large in all phases of elaboration of R&I processes, starting with agenda and priority setting. It is strongly related with the discussion on the role of communities (see A3.3), as well as to the need to address interdependencies (see A5.2) and have a multiplicity of descriptions (see A6.1). This dimension gives its full meaning to human agency in the context of R&I, which is now limited to the small elite of institutions developing R&I activities (see A3.2). Also, it opens the door to consider mutual learning as the most effective way for transformation (see D2.3).

Responsiveness points to the need for R&I processes to respond to societal evolution and challenges, which is insufficiently covered in existing R&I configurations. This can be seen as a challenge with multiple faces. As the major goal of RRI, the alignment of R&I processes with societal values, needs and expectations is an aspiration in which none of the components is completely well defined nor static, like playing darts with a moving board. This is related to the absence or insufficiency in R&I agendas of elements expressing the aspirations of humanity (see A4.4 and A4.5). It also derives from a framing of R&I leaning towards technology while many other facets are relevant for positive transformations (see A3.5). And it has to build upon the known limitations of conscious purpose (see A1.4) and other approaches to the question of how complex systems can change in a desired direction (see Section A5 and D2.3).

Anticipation is about the dependency between our current R&I processes and their future consequences. On one side, as discussed in A3.1, existing R&I processes have created a number of negative consequences which are not collateral and have to be addressed. On the other, the future consequences of current R&I processes need to be considered as well. This is very much related to the systemic and in particular cybernetic nature of reality (see A2.3, A2.5). Different lines of thought exist regarding anticipatory studies, most of them not based on the perspective of complexity, and hence generally misleading. Anticipation cannot just be an extrapolation of the present. It has rather to build upon the best of our understanding of complex systems (see Section A5) and capacities for collective deliberation (see A6.1) and mutual learning (see D2.3).

A3.5. TRANSFORMATIONS

In the SeeRRI approach, research and innovation are expected to have a transformative role, in the sense of the term "transformation" associated with the UN Agenda 2030 of Sustainable Development Goals (SDGs) [UN 2015]. The SDGs do not point to superficial adaptations or incremental improvements: starting with the huge change in metabolism from fossil fuels to renewable sources of energy, they mean no less than a complete overhaul of human civilizations. The other option is as dramatic but much less pleasant: if the SDGs are not achieved, the chances of self-destruction of humanity at scale increase exponentially. So, there is little doubt that all means have to be mobilized, including the capacities provided by R&I activities.

But reality admits multiple descriptions. And the reflection on our systemic dysfunctions and how to solve them also admits multiple approaches. The challenge may be daunting if we recognize that everything is interdependent on everything else (see A2.2, A2.3 and A5.2). This is why, as manifestations of present challenges become more evident, simplistic answers to complex crises are proliferating. This is not the path of SeeRRI, the project dares to face complexity because dismissing it is, to the best of our knowledge, a wrong approach.

The following is a non-exhaustive description of levels or perspectives of transformation. The depth of the challenges and hence of the responses to them is such that there is no straight pathway from A to B in ten easy steps. Transformation will be shaped by a complex ecology of ideas and initatives that are interconnected and not mutually exclusive. The SeeRRI Conceptual Framework does not address all the following levels, but the landscape they form is useful as a background to the use of the framework in SeeRRI and beyond.

Technological Innovation is one of the perspectives, probably the most prevalent when talking about the future. Transformations are happening everyday and technology plays a significant role in them. Moving from the use of fossil fuels to renewable sources of energy is, to a large extent, a technical and technological challenge. Expectations are high that technologies could contribute to addressing the contradictions of our development models. Most notably biotechnologies (including biomimicry), genetic engineering and digitalization (including Artificial Intelligence) are invoked. Learning more from biological processes and using our capacity to acquire, transmit and process information seem to be promising, however the framing of science and technology could either bring solutions to our existential risks or simply accelerate the same trends we need to avoid.

Regenerative and Wellbeing Economics is a vast domain of thinking and action involving many activists, academics and entrepreneurs throughout the world, in many cases in local communities. It is also attracting growing attention from governments (New Zealand, Iceland, Scotland, Costa Rica, and others). If we intend to shift our societies, rethinking economic and financial processes is mandatory, transforming the ways we produce and consume, and also the ways we invest. In that rethinking, achieving wellbeing for humans should not be in contradiction to a healthy biosphere (see A4.3 to A4.5). Circular economy and decoupling wellbeing from resources are parts of the responses. But they are more rapidly proclaimed than executed. The crisis of the "gilets jaunes" in 2018-2019 in France raises this question: is getting to the end of the month contradictory to preventing the end of the human species? Hopefully not, but the question rightly connects the issues of social inequality and environmental sustainability. Putting prices on the environment (on trees and lakes and birds...) is not a way to solve the dilemma. On the contrary, we should recognize the incommensurable value of life and restrict the use of money to where it is really useful. Economics must be freed from incumbent dogmas if we want to start questioning policies in inconvenient and fruitful ways. Some questions are old, some are new, but there is no way that unlimited growth of material throughput in a finite planet can continue to be the main part of the answer.

For many, the transformation of economic processes cannot happen without a shift in our behaviour as consumers. This is one of many reasons to address **Inner Transformation** as another perspective of systemic change. It is a call to individuals to move from awareness and the anxiety it brings, towards higher levels of consciousness about our relationships with others and with nature as a whole. In this perspective the role of education is obviously critical, not only for coming generations but also for lifelong learning as a process combining individual and collective transformations. Some examples of successful and peaceful transitions from agrarian to industrialized societies in Nordic countries may be explained through this approach. But the acquisition of new capacities to adapt individually to a new but already existing paradigm (the industrial revolution) seems to be easier than the exercise we have in front of us. Individual transformation by itself could hardly produce the creation of a new paradigm. And the risk exists that the present obsession on individual performance overrides the collective dimension.

The perspective of **Collective Leadership** is a structured attempt to respond to the insufficiencies of our governance systems, in particular regarding global limits and the protection and development of common goods. It emphasizes the process of transformation itself rather than predefined goals. Taking into account the complexity of issues without intention of reductionism (see A2.2), this approach relies on our capacity to create new pathways through collective deliberation among stakeholders. Instead of an omniscient conception of enlightened government from the top, it promotes the stewardship of sustainability transformations at multiple scales [Künkel 2018]. Some stakeholders will be reluctant to adopt perspectives not compatible with their established interests. Some institutions may not have enough flexibility to overcome their own arrangements of control and command. The ultimate pitfall for collective leadership is that the establishment profiting from the existing distribution of power may not accept a new paradigm without domination and exploitation.

Another important perspective comes from questioning the whole process of modernity by listening to usually unheard voices and adopting the lenses of so many cultures and societies which have been dismissed and almost obliterated. Not to replace the Western perspective by the non-Western, rather to admit that everything human is contextual, that a multiplicity of views is possible and desirable and that trans-contextual analysis is required to acknowledge complexity (see A6.1). **Ubuntu**, the African philosophy stating that "I am because we are" is a humanist approach to hold the complexity of interdependencies (see A5.2). It also connects with the wisdom of indigenous societies who have managed to survive in some parts of the world with a completely different and more harmonious relationship with nature. Note that China has officially adopted the goal of becoming an "ecological civilization", and that Japan prides itself on an appreciation of balance and its experience in dealing with emergencies. Understanding the interconnectedness and richness of what makes us human might open more windows into the feeling, intuitive and non-verbal communications within and between us. It would also help us feel and get closer to nature in a sensual way that makes us better attuned to living in harmony with it.

Our relationship to complexity is omnipresent in SeeRRI. And it is demanding: we have to escape the tempation of thinking about complexity in a non-complex way. Living systems are flows of interdependencies among large numbers of autonomous agents (cells, living beings, organizations,...), from which myriads of networks, structures and forms can emerge in self-organized ways. Contexts and scales are not separated and their connections can make a difference, especially at critical points where the behaviour of a system can shift completely. This approach builds on holistic perspectives rather than reductionism (see A2.2). Instead of separation, it puts interdependencies at the core (see A5.2). Which requires accepting essential uncertainty, and questioning dualism and objectivity by recognizing the need to observe the observer and the mental frameworks in use. This approach also questions rationalism in that cognition processes are themselves complex: reality is not fully accessible to our conscious mind (see A1.3 to A1.5). But at least our limited access is enough to make us aware of our limitations. Let us assume then that complexity and uncertainty are foundations for the emergence of life and that knowledge does not bring certainty nor predictability except at local levels (see A6.7). Adopting such a perspective means a shift in our relationships with ourselves and the world. **Embracing Complexity** and **Dancing with Systems** make us more aware of the constant process of mutual learning in interaction with the ecosystem of which we are part, a learning relying on aesthetics, beyond what we are able to express in any single language (see A1.3).

This multi-level description seems to be beyond the reach of usual research and innovation activities. This would be true if we had to continue making R&I equivalent to the crafting of ingenious new artifacts derived from latest advancements in science. But with the much more ambitious goal of contributing to the transformation of human civilizations, nothing less than a holistic perspective is required. This is the topic of Sections A4 to A6.

A4. NATURE AND US

The title of this Section is deliberately provocative. It implies that humans are not part of nature, which of course is not true. But this idea of separation is a common blind spot in the way we think about our relationship with nature, as something different from human-made environment, and also in the frequently invoked dichotomy between nature and culture. This is an example of the type of blind spots created by the "fantasy of exclusion" (see 2.5), and the purpose of this Section is to analyze the topic from the modern perspective of ecology, in which the distinction does not lead to exclusion and we realize how much interdependent we are with nature.

A4.1. BIOSPHERE, ECOLOGY AND BEYOND

The term "biosphere" originates in geology and was coined in 1875 by Eduard Suess to designate the part of the Earth´s surface where life happens. Today it is generally used to represent the totality of all ecosystems on Earth, and is sometimes also referred as the "ecosphere". It is also used to designate any closed, self-regulating system containing ecosystems, including artificial ones such as Biosphere 2 (an experimental research facility of the University of Arizona) and BIOS-3 (at the Institute of Biophysics in Krasnoyarsk, Russia). From this meaning is derived the term "biospherics", a discipline dealing with artificial models of Earth´s biosphere and hypothetical non-Earth biospheres, human or not.

The concept has evolved over time and has different interpretations depending on the lens used, whether from a particular discipline or with a transdisciplinary approach. In the context of geochemistry four separate components are considered: the geosphere (as the set of all solid parts of the Earth), the hydrosphere (liquid parts), the atmosphere (gaseous parts) and the biosphere as the sum of all living organisms (also called "biomass" or "biota" by biologists and ecologists). Though sometimes used as an equivalent of biosphere, the term "ecosphere" originated in the 1960s and is meant to encompass both biological and physical components of the planet, hence including the four geochemical components mentioned above.

The emergence of ecological thinking in the first decades of 20th century transformed the conception of the biosphere. The term "ecology" itself had been coined in 1866 by zoologist, artist and writer Ernst Haeckel by combining ancient Greek words to express the concept of "the study of our house". Ecology is considered as a branch of biology dealing with the interactions among living organisms and their biophysical environment, which includes both biotic (living) and abiotic (non-living) components. Ecology builds upon a very long tradition of observation of natural life and biological systems, with relevant contributions by Hippocrates, Aristotle, Herodotus, microscopist Antoni van Leeuwenhoek in 17th century, botanist Carl Linnaeus in 18th century, naturalist Jean-Baptiste Lamarck in late 18th and early 19th century, Alexander von Humboldt in early 19th century and Charles Darwin in second half of 19th century. Botanist Eugen Warming, contemporary of Haeckel, is considered as the co-founding father of ecology.

In the conception of ecology the idea of evolution is a dramatic change of epistemology. Leaving behind the consideration of the natural world as static and unchanging, ecology became an effort to understand the dynamic and reciprocal relations between organisms, their adaptations and the environment. That change is certainly related to the (controversial) acceptance of the theory of evolution through natural selection, independently and simultaneously fathered by Alfred Russel Wallace and Charles Darwin. But as early as in 5th century BC, Herodotus identified an interdependency between species by describing how sandpipers take care of the dental hygiene of crocodiles by plucking leeches out of their open mouth. Birds are fed, crocodiles keep their teeths clean: this is a simple but astonishing example of mutualism in nature. Much later, in the middle of 18th century Lamarck already provoked a revolution by turning upside down the hierarchy of nature, which until then was supposed to go down from divinity as the supreme mind to man and then to animals, all the way down to microorganisms. Lamarck postulated a huge epistemological shift, by stating that life history starts with microorganisms and through many changes leads to the appearance of animals and humans [Bateson 1968]. The evolutionary theory of Russel Wallace and Darwin has many other precursors, as Gilbert White, an amateur naturalist whose *"Natural History and Antiquities of Selborne"* (1789) is considered now to be one of the earliest texts on ecology.

The consolidation of evolutionary biology at the very end of 19th century facilitated the emergence of a stronger ecological thinking in the first decades of the 20th. Vladimir Vernadsky met Eduard Suess in 1911 and elaborated on the concept of biosphere, giving to it a wider meaning than originally intended by Suess: in Vernadsky´s perspective, ***the biosphere is the global ecological system integrating all living beings and their relationships, including their interaction with the elements of the geosphere, hydrosphere and atmosphere***. And Vernadsky defined as well ***ecology as the science of the biosphere***, necessarily an interdisciplinary endeavour since it integrates all life and Earth sciences, geophysics, meteorology, hydrology, geochemistry, biogeography, evolution, and many others. As one of the first scientists having recognized that the oxygen, nitrogen and carbon dioxide in the Earth's atmosphere result from biological processes, Vernadsky and others opened the door to an evolutionary perspective of the biosphere as a whole, i.e. as a largely self-regulating system closed except for the inflows of energy from solar and cosmic radiation and heat sources from the interior of the Earth. In that conception, the biosphere has an history starting at least some 3,5 billion years ago with processes of "biopoeis" (life created naturally from non-living matter) and "biogenesis" (life created from living matter). Preceding the introduction in 1935 of the term "ecosystem" by Arthur Tansley (see A4.2), Vernadsky proposed during the 1920s the idea that living organisms could reshape the Earth as surely as any physical force, an anticipatory vision of the modern concept of the Anthropocene [Steffen et al 2007] as a new geological era shaped by humans.

Going substantially further and in parallel with philosopher and theologian Pierre Teilhard de Chardin, Vernadsky first popularized the concept of "noosphere" (from Greek "noos" for mind or reason). This is the idea that after the geosphere (inanimate matter) and the biosphere (biological life), the Earth is now in its third stage of development. As the emergence of life fundamentally transformed the geosphere, the emergence of human cognition is fundamentally transforming the biosphere. This systemic perspective integrates the theory of natural selection, which looks at each individual species, in a wider picture. But, one may ask, is the noosphere a further step in evolutionary development or will it end by itself because of its destructive relationship with the biosphere?

A4.2. ECOSYSTEMS

The term "ecosystem" comes from biology and it was first used in 1935 by ecologist Arthur Tansley. It designates an assembly of living organisms in conjunction with the non-living components of their environment, interacting as a system and linked together through nutrient cycles and energy flows. Initially the concept was used to put emphasis on the exchanges of materials between organisms and their environment. Nowadays the term is also often used in non-biological contexts (e.g. in business management or innovation studies) as a metaphor to designate systems sharing some of the characteristics of natural ecosystems.

Ecosystem ecology is the integrated study of living and non-living components of ecosystems and their interactions within an ecosystem framework. This is a good case in point on the dependence between the framework and the analysis (see A1.1). What constitutes the boundary of an ecosystem is a matter of choice and if we consider that all interactions are relevant there is no "objective" way to define that boundary since completely isolated ecosystems do not exist. In a way the whole ecosphere is one ecosystem, the only one which is closed from the point of view of material exchange with the outside, but at the same time open from the point of view of energy exchange. The best which can be done when analyzing a particular ecosystem is to make explicit the assumptions of the framework, and especially where the boundary is set. Ecosystem ecology puts the focus on functional processes, those ecological mechanisms that maintain the physical and biological structures, especially from the point of view of what we interpret as the "services" produced by the ecosystem. These include the primary production of biomass as well as the decomposition of organic matter and the interactions in trophic chains (e.g. herbivores eating plants and being eaten by carnivores). Note that this idea of a production of services by ecosystems is an example of epistemological transfer: the concept comes from human economics and is used to analyze natural ecosystems as if they existed to serve a particular purpose useful to humans. It can be argued that this anthropocentric perspective of ecosystems is among the foundations of our currently conflictual relation with nature.

In the context of SeeRRI it is interesting to outline the outstanding features generally associated to ecosystems, whether they be actual in the case of natural ones, or intentional in the case of human creations (e.g. a business network):

- They are dynamic entities, perpetuously changing and evolving. They are influenced by internal and external factors, and subject to disturbances (as said above, what is internal or external is largely a matter of choice on the boundary of the ecosystem);

- Their vitality depends on flows of energy and materials (in-, out- and internal flows);

- They are dependent on many aspects of context. E.g. ecosystems in similar environments but located in different parts of the world can have very different pools of species;

- Resilience, the ability to recover from disturbances, is a built-in or expected characteristic. Ecosystems are self-corrective against disturbance, through the emergence of feedback loops. Without this characteristic ecosystems would be unstable and collapse sooner or later;

- Diversity contributes to resilience: highly uniform natural or human ecosystems are fragile. Hence the critical importance of biodiversity;

- Causality chains can be complex and take a long time to act. Climate warming is a case in point. Not only feedback loops abound, the chains of events leading from one factor to its ultimate consequences can cover large circles [Bateson 2016].

Among the factors influencing the behavior and health of a natural ecosystem, distinction is made between factors deemed to be stable over long periods of time, such as topography, parent material (the underlying geological material in which soils form) or climate, and more rapidly changing factors. The stable factors are generally considered external, influencing the ecosystem but not being influenced by it, while the changing ones are considered as internal. But with the development of ecosystem ecology, awareness is growing on the complexity of interdependencies keeping an ecosystem in a healthy state or disturbing it and potentially making it collapse. Boundaries of ecosystems are not only arbitrary but increasingly blurred.

Before becoming scientific mainstream (which it is not fully yet), this awareness of complexity originated in the realization of the negative consequences of human action on natural ecosystems. In 1962, marine biologist Rachel Carson published *"Silent Spring"*, an environmental science book warning against the irresponsible use of synthetic pesticides potentially leading to the disappearance of birds (hence the silence in the title). The book created controversy and backlash by the chemical industry but its publication was one of the historical events leading to the onset of environmental consciousness (and to the ban of DDT for agricultural uses). Again, this represents an epistemological shift: from an ecosystemic perspective it is not so relevant to know if the negative impacts of DDT were unintentional, what really matters is if our conceptual framework was blind on the potential consequences of our actions or not. While collapses of ecosystems are not new in the history of evolution and can be provoked e.g. by the introduction for whatever reason of non-native species, what is new is the intensity of the impacts of human action on all ecosystems across the planet, of which climate warming and the emergencies it induces are the most spectacular. There its very little true wilderness left, ecosystems with no direct human intervention. But now even those are affected by human metabolism. Hence the study of ecosystems can no longer be free from the analysis of the human footprints on Earth.

A4.3. ECOLOGICAL FOOTPRINT

Over last decades there have been a number of attempts to identify and raise the awareness on the profound modifications affecting natural ecosystems due to human activities. Generally those attempts have been of a partial nature, addressing specific aspects in terms either of consequences, causes or places. The most publicized nowadays is the global awareness on climate warming. Decades of work by the UN Intergovernmental Panel on Climate Change (IPCC), created in 1988, have led to a wide scientific consensus on the causal relationship between the emissions of CO_2 and other greenhouse gases, mainly due to the combustion of fossil fuels, and the unprecedented rise in the average temperature of the atmosphere. If unchecked, this will have (and to an extent is already having) disastrous consequences on the living conditions for humanity and all other species. The work done by the IPCC is probably the most ambitious human project to date in the discipline of anticipation, and it represents an outstanding exercise of scientific responsibility (which no doubt influenced the emergence of RRI as a policy). The most ambitious because the topic (the evolution of atmospheric climate at global level) is of dauting complexity, both intellectually and technically, and addressing it has required the mobilization of thousands of scientists and all kinds of resources around the world during decades. The effort in research and communication led to the crafting of a universal and legally-binding political agreement among UN states to tackle global climate change: the Paris Agreement adopted at the COP-21 conference in December 2015 sets a global framework to limit global warming below 2ºC. Unfortunately, that success at the level of multilateral institutions has not been followed by practical success: progress is not being significantly made in the reduction of GHG emissions worldwide (except not due to the Covid-19 crisis) and the USA even decided to withdraw from the Paris Agreement. This is in contrast with the success of an earlier and often cited precedent dealing as well with the consequences of human activity but with a much more limited scope: the Montreal Protocol agreed in 1987 proved to be an effective instrument to phase out the production of sustances responsible for the depletion of the stratospheric ozone layer (mainly chlorofluorcarbons present in aerosols).

In recent times attention is increasingly being paid to the loss of biodiversity, as a consequence of the activity of the UN Intergovernmental Science-Policy Platform on Biodiversity and Ecosystems Services (IPBES), which intends to play a role similar to the IPCC through the publication of periodic reports warning of the degradating state of biodiversity, the high level of species extinctions and the threats this brings for the survival of humanity itself. Many other initiatives have been looking at specific aspects of the manifold impact of human activities on the natural environment in more local ways, monitoring and warning about the degradation of specific ecosystems. And many organizations have been created in the last decades to that purpose, e.g. the World Wide Fund for Nature (WWF). Overall, all those initiatives deal with aspects of reality separated from the rest: they may have a systemic approach on the topic of their choice (this is certainly the case with climate modelling) but have defined boundaries which impede them from going into the interdependencies between their topic and all other dimensions of human activity. In particular, ecological perspectives have been typically disconnected from social and economic perspectives, which main explain why, in a world which to a large extent has officially adopted the discourse of ecological preservation, not enough political will has been built up to put it in practice. A holistic and systemic perspective is much needed at this level, starting with a more comprehensive assessment of the metabolism of our relationship with the biosphere of which we are part (and a substantial one).

In the early 1990s Mathis Wackernagel and William Rees defined the concept of **Ecological Footprint** (EF) as a metric measuring how much area of biologically productive land and water an individual, population or activity requires to produce all the resources it consumes and to absorb the waste it generates, using prevailing technology and resource management practices. GFN was established to provide reliable measurements of EF over time and at different scales (global, national and local), taking also into account the relevant contribution of trade: since it is global, an individual or country’s footprint includes land or sea from all over the world. The EF can be measured in global hectares per person, or in the more intuitive "Number of Earths", which represents how many planets Earth it would take if everybody had a specific footprint. To measure whether we live within the means provided by nature we can take into account that less than 1,7 global hectares per person or, by construction, 1 Earth per person, makes the resource demand globally replicable within the limits of our planet [Wackergnagel & Rees 1996].

Complementarily to EF, **biocapacity** (also measured in global hectares per person) represents the ability of a particular area to produce biological materials used by humans and to absorb human-produced waste, under current management schemes and extraction technologies. It measures the capacity of ecosystems to regenerate what people demand from them.

To be clear, these indicators of EF and biocapacity do not provide a completely comprehensive representation of the challenges that human societies face. Many relevant aspects are not taken into account, e.g. social inequalities, biodiversity losses, the planetary boundaries [Steffen et al 2015], the exhaustion of non renewable resources or the extraction of critical mineral elements [Valero & Valero 2015]. But they are useful in providing an overall outlook and a compelling graphic representation, provoking enough to open minds and to initiate new conversations on these issues of critical importance for the future of humanity, also in educational contexts [Gottlieb et al 2013]. As shown in figure A14, at a global level we entered in the 1970s in an increasingly unsustainable regime in which the global Ecological Footprint is higher than the Earth´s biocapacity. In other words we are consuming natural resources at a rate higher than the planet is able to produce them (nowadays it is 70% higher), which leads to the destruction of the reserves of natural ecosystems, a very dangerous path downward. This is obviously not good news and calls for a dramatic reduction in global EF, as will be discussed more in detail in A4.5.

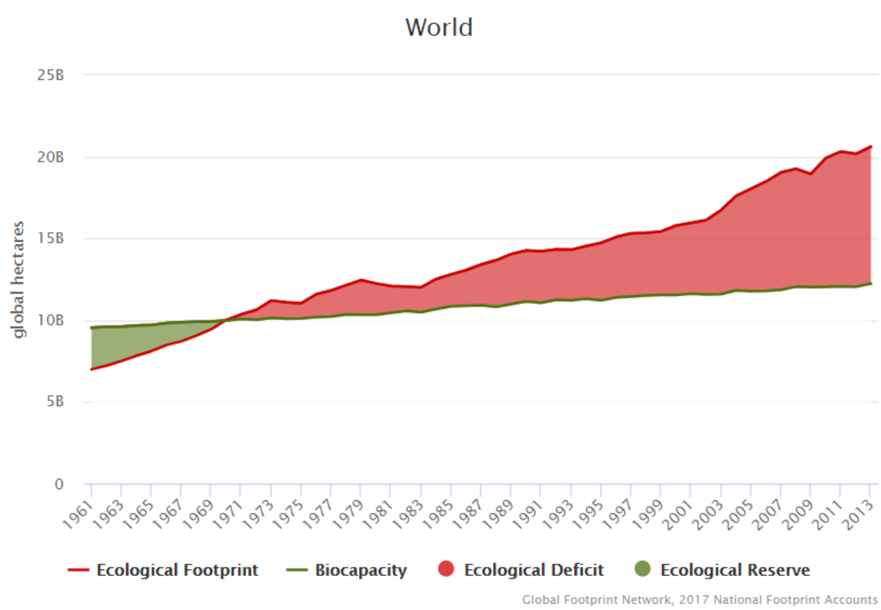

Figure A14. Worldwide evolution of biocapacity and footprint, 1961-2013 (source: GFN)

In the case of SeeRRI, these metrics can be used to contextualize the situation of the three territories involved in the project. Although data are not available for the specific territories, the national indicators give some useful hints. Evolutions are represented in figures A15 to A17.

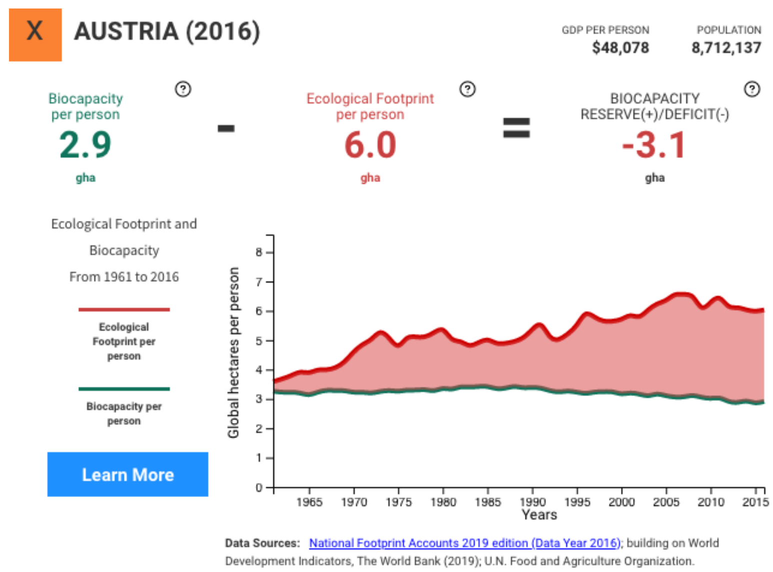

Figure A15. Austria: evolution of biocapacity and footprint, 1960-2016 (source: GFN)

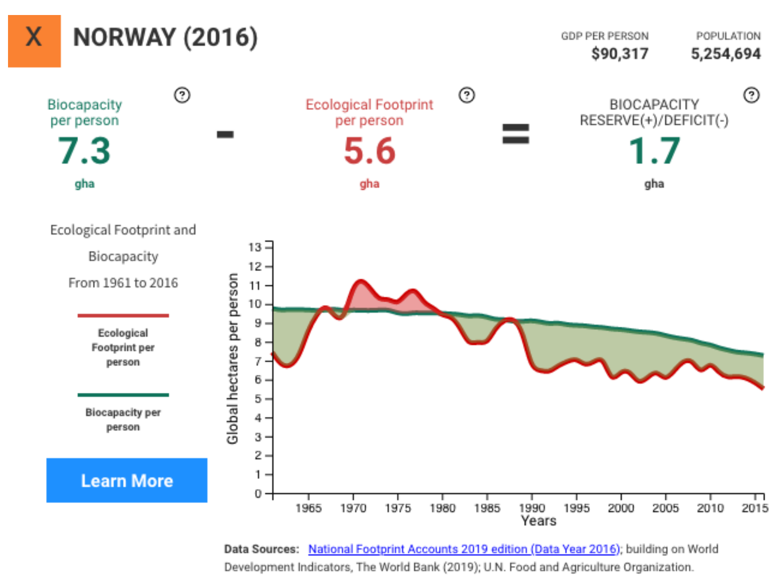

Figure A16. Norway: evolution of biocapacity and footprint, 1960-2016 (source: GFN)

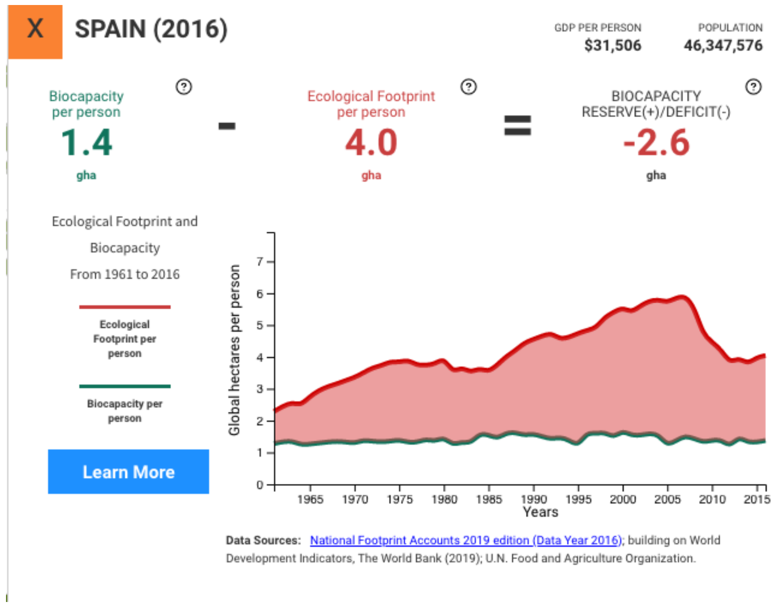

Figure A17. Spain: evolution of biocapacity and footprint, 1960-2016 (source: GFN)

As the figures show, the three countries have quite different patterns. Regarding their Ecological Footprints (EF):

- In Austria and Spain, the EF has grown substantially in the last 50 years: from 3,5 to 6 gha/px in Austria and from 2,5 to 6 then down to 4 gha/px in Spain. It is interesting to notice that in the aftermath of the crisis of 2008, Spain reduced its EF by one third in less than 10 years;

- Norway has experienced a consistent decline in its EF from a peak of 11gha/px in the early 1970s down to 5,6 gha/px in 2016. This level is still very high but along with the Spanish case this shows that substantially reducing the Ecological Footprint is not impossible and does not necessarily entail a collapse in human wellbeing. The case of Norway deserves further investigation.

Regarding biocapacity and ecological deficit or reserve:

- Due to different territorial conditions and population densities, the three countries have very different biocapacities per person: Spain is lowest with 1,4 gha/px, Austria has 2,9 gha/px and Norway 7,3 gha/px;

- Consequently, their situation in regard of national deficit or excess (biocapacity - footprint) is totally different: while Norway has a positive balance of 1,7 gha/px, Austria and Spain have similarly negative positions (-3,1 and -2,6 gha/px, respectively);

- The differences in evolution over time are also noteworthy. In Austria, biocapacity has been initially stable and then slightly declining since the 1990s, while its footprint grew rapidly until 2005 and then stabilized;

- In Norway, biocapacity has been significantly declining, especially since 2005, and its footprint increased from the 60s to the 70s and has been declining most of the time since then;

- In Spain, biocapacity has been extremely stable over the whole period from the 1960s, while its footprint grew rapidly until around 2008 and then collapsed; it has stabilized and now shows signs of growth once more.

A4.4. HUMAN DEVELOPMENT AND ITS MEASUREMENT

Human development is a wide topic in itself, we only highlight here what is more relevant to the context of responsible innovation in general, to SeeRRI in particular and to the possibility of conciliating genuine human development with the physical finitude of the biosphere of which we are part. Historically the concept of development has been associated to the rapid process of industrialization and urbanization that has characterized the evolution of certain countries in the last two centuries and nowadays has become the benchmark for most of them. In turn the framing of this process and its evaluation have been dominated by a few statistical measurements at national level and their comparison across countries: total population, Gross Domestic Product (GDP) and GDP per capita. GDP is a monetary measure of the market value of all goods and services produced in a specific period (typically a quarter or a year). Simon Kuznets, the father of national accounting in the USA and the man who crafted the first calculations of GDP in 1934, clearly advised that:

> *"The welfare of a nation can scarcely be inferred from a measurement of national income as defined by the Gross Domestic Product."*

Nonetheless, the GDP and its ratio per capita became the metrics of reference to measure and compare degrees of development in different countries. In the decades after World War II their rates of growth became the preferred indicators for governments and economists to sense the good health of an economy (concerns about inflation came much later, in the 1970s) and ultimately the degree of development of a society. In the first decades after 1945, the process of economic development went so fast tha almost nobody questioned it, beyond the fact that there were two models of development, the capitalist one led by the USA and the socialist one led by the USSR, which were political rivals and even adversaries, but shared the same philosophy of human development through industrialization, urbanization, modern science and technology. In the late 1960s and early 1970s the Club of Rome disrupted the global conversation about development by raising the alarms about the unsustainability of any model based on the assumption of the absence of limits to economic growth as measured by metrics such as GDP [Meadows et al 1972]. That had a huge impact and was the first step of an epistemological shift not yet completed today, and it was responded by coining the concept of "sustainable development" in the context of the United Nations:

> *“Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:*
> *- The concept of ‘needs’, in particular, the essential needs of the world’s poor, to which overriding priority should be given; and*
> *- The idea of limitations imposed by the state of technology and social organization on the environment’s ability to meet present and future needs.”* [WCED 1987]

As we will see, 30 years later sustainable development is still an oxymoron (see A4.5). Maybe it could not be otherwise, since the concept was by construction hybrid: it did not disrupt the previous framing of ongoing processes of development but added the requirement that they should be compatible with the preservation of the natural environment. In the definition above a mechanistic epistemology is still very much present: the reference to "*the environment’s ability to meet present and future (human) needs*" clearly separates us from the environment and puts it at our service. This conceptual framework does not reflect the depth and intensity of our mutual dependencies with nature within the biosphere.

Over time, the critique of the conventional framing of development addressed multiple aspects, not only its potential conflict with sustainability. It became clear to many that the GDP could not be the ultimate measure of human achievements: in1968 (the same year the Club of Rome was founded), Robert Kennedy expressed it in an eloquent manner:

> *"Yet the gross national product does not allow for the health of our children, the quality of their education or the joy of their play. It does not include the beauty of our poetry or the strength of our marriages, the intelligence of our public debate or the integrity of our public officials. It measures neither our wit nor our courage, neither our wisdom nor our learning, neither our compassion nor our devotion to our country, it measures everything in short, except that which makes life worthwhile."*

In the 1980s the concept of "uneconomic growth" emerged, coined by ecological economist Herman Daly to designate economic growth which actually creates decline in quality of life. Along those thoughts, Marilyn Waring (one of the founders of the field of feminist economics) proposed a number of ideas leading in the early 1990s to the creation of the Genuine Progress Indicator (GPI), a tool constructed to screen out the negative effects of economic growth. It uses a composition of 26 different indicators which are added or subtracted depending on their contribution to quality of life (e.g. the effects of environmental degradation, the costs of crime, the loss of leisure time and the cost of commuting are included with a negative sign). Worryingly enough, the evolution of GPI shows that, at least in the USA, it is stagnant since the 1970s and has completely decoupled from the growth in GDP (see figure A18).

In 1990 the UN Development Program, under the impulse of the economist Mahbub ul Haq, started elaborating a composite index to reflect three fundamental aspects of human development blended altogether into one metric: health (represented by life expectancy at birth), education (represented by the average years of schooling) and prosperity (represented by average income per capita). With these components was created the **Human Development Index** (HDI) [UNDP 1990]. A level of HDI higher than 0,7 is considered as "high human development". In 2011 the Organization for Economic Cooperation and Development (OECD) launched its Better Life Index, following the recommendations of the Commission on the Measurement of Economic Performance and Social Progress (aka the "Stiglitz-Sen-Fitoussi Commission") which had been established in 2008 by the French Government in the aftermath of the global financial crisis. The Better Life Index is an interactive tool taking into account 11 dimensions intending to reflect different quantitative as well as qualitative aspects of quality of life in different countries (housing, education, happiness, work-life balance and so on).

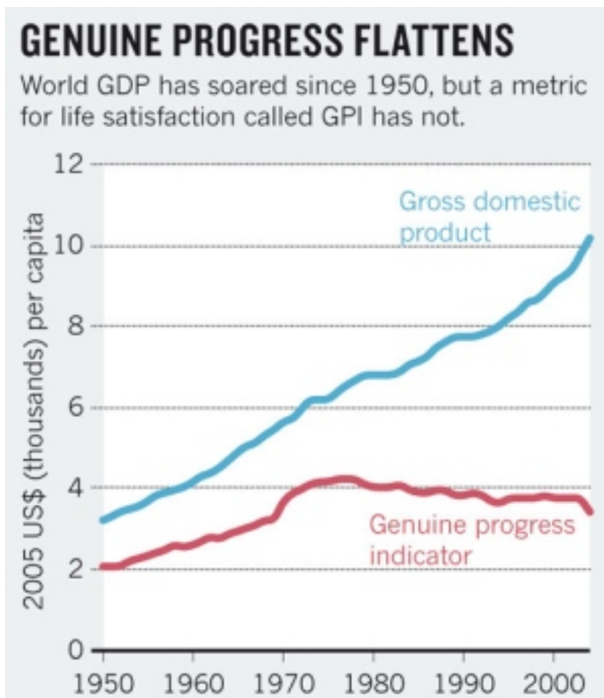

Figure A18. The decoupling of GDP and GPI in the USA (1950-2004) (source: Redefining Progress)

The same year of 2011 the UN General Assembly passed the resolution "Happiness: towards a holistic approach to development" urging member states to follow the example of Bhutan and use measurements of happiness as guidance for good governance. In 1979 the King of Bhutan had famously said that *"Gross National Happiness is more important than Gross National Product"*, which led years later to the implementation of a composite index to measure GNH based on four pillars:

- sustainable and equitable socio-economic development,
- environmental conservation,

- preservation and promotion of culture, and
- good governance.

All these reflections and initiatives had in common a certain amount of frustration about the conventional framing of human development and its reduction to economic growth as measured by the GDP. After a substantial multilateral effort over several years, the United Nations launched in 2015, with the unanimous support of the member states, the Agenda 2030 of Sustainable Development [UN 2015]. This intended to be a new and holistic framing for human development, reflecting on 17 different dimensions or Sustainable Development Goals (SDGs, see fig 20).

Figure A19. The framework of the SDGs [UN 2015]

The SDGs framework has now become the official framing to define what has to be taken into account as far as human development is concerned. It is supposed to inform public as well as private agendas at whatever level (local, regional, national or global). A political mandate exists to deliberately align all processes of societal evolution with the SDGs, including the processes of Research and Innovation. It is difficult to say how much of that alignment has been achieved but from a political point of view, there is consensus that doing otherwise could not be considered as "responsible".

Then, in the light of RRI, using the SDGs as a compass to navigate the evolution of R&I processes seems to be the natural option. But how do we know if concrete activities are aligned with the SDGs? How can they be used as a compass for the navigation of societal evolution? Is it possible to assess the current patterns of societal development in a territorial community against the 2030 Agenda, in order to build a shared vision of the Responsiveness that is demanded from R&I processes in that territory, as part of the RRI policy? The intention of the SDGs is certainly to balance the many dimensions of human development with the critical considerations on the negative impacts on the biosphere. The SDGs framework is composed of 17 goals and 232 indicators: potentially one could imagine computing the impacts of human activities (e.g. of R&I projects) according to that framework. But reconciling this option with the epistemological shift we need is a challenge in itself. From a systemic point of view the goals and indicators are not independent dimensions: they are fully interdependent. Reality cannot be splitted into sealed compartments, and considering it otherwise can easily lead to a nightmare of entangled trade-offs. Also, the imagined exercise could be misleading: to continue with the metaphor of navigation, we would need a dynamic sense of wind direction and intensity as well as a tentative course to where we want to go, rather than a long list of quantitative indicators which will always deliver mixed signals: some will be good, others will be bad, on many we will not know what is going on. This particular challenge of "societal navigation" is one of the obstacles for translating global debates on sustainability into concrete actions in concrete territories. This contrasts with macroeconomic governance, simply driven by the goal of keeping GDP growth at the highest possible level compatible with moderate inflation (whether the goal is appropriate or if it is even achieved in a sensible way is another issue). This also means that the alignment of macroeconomic policies with the SDGs is taken as a secondary aspect, not as the main goal of economic governance.

Moreover, as discussed in A2.1 and A2.2, splitting the monitoring of societal evolution into 17 SDGs and 232 indicators seems precisely the kind of mechanistic exercise at odds with real-world complexity. We rather need to engage in a process of mutual learning for which we do not yet have recipes (see D2.3). This process starts with open deliberation, as has been initiated with the partners and stakeholders of the SeeRRI project. At the same time, some kind of overall guidance is probably welcome to orient the deliberation. One idea for that purpose is to use a more synthetic compass than the multifaceted structure of the SDGs. This is not to say that the use of fewer indicators is less mechanistic than using more, but if the synthetic indicator is well chosen, it could be useful in provoking relevant questions, which is the first step towards mutual learning. Monitoring is not useless, but it depends on the expectations we have. If we believe that a set of indicators can truly represent the complex patterns present in society, we are probably misled. However, if we use the indicators as alarms leading to uncomfortable questions, that could be useful as a focal point for our inquiry. Our concrete proposal for this synthetic compass is to **consider the state of societal evolution by looking at how much human wellbeing is achieved at what level of ecological footprint**.

A4.5. WELLBEING(S) IN BIOSPHERE

In recent years the concept of wellbeing has acquired more prominence in the debates related with the insufficiency or inadequacy of GDP as societal compass. The term may have many different meanings but it has become the center of new worldwide conversations about the redefinition of progress to get out of the paradox of more GDP leading to worse quality of life. It also integrates the notion that no long-term wellbeing can be achieved at the expense of the biosphere of which we are part. The concept of "wellbeing economy" is being adopted by some governments as a the new compass of their social, economic and environmental policies, often under the leadership of a new generation of women in politics (as in New Zealand, Iceland and Scotland).

In this context it seems appropriate to reframe the idea of human development, taking into account the many negative consequences of the current model of development: climate warming, loss of biodiversity, rapid rising of social inequalities, exhaustion of non-renewable resources, degradation of natural habitats, and so on. All of these have expanded so much as to be collectively considered as self-inflicted existential threats. And they are intertwined in a way which exposes our fragility: the impacts of Covid-19 are manifold and they have been nurtured not only by the zoonosis itself (as a result of an increasing pressure on natural habitats) but also by the combination of massive urbanization, air pollution and globalized logistic chains.

In the context of SeeRRI as a project promoting Responsibility in processes of R&I in territorial contexts, we propose to use the concept of **equitable wellbeing at peace with a healthy biosphere**, in short "wellbeing in biosphere", as the North pole of our compass to navigate the evolution of R&I processes towards Responsibility. We also consider that the pathways towards the realization of that concept could not be based on universal recipes applicable in the same way to all places and cultures. They are necessarily dependent on territorial contexts, as is developed in the project. This is why the "s" is added in "wellbeing(s)", to indicate that the same and abstract concept can mean different things in different places. To get an overall feeling of the magnitude of the implied challenge, we can use a provocative representation of **how much human wellbeing is achieved at what level of ecological footprint**, based on indicators for which there is already evidence and historical series, such as the Human Development Index (HDI, see A4.4) and the Ecological Footprint (EF, see A4.3). The use of a few indicators cannot replace the whole complexity of the issue, but by combining these two we can have an initial insight shedding some light on existing blind spots (see A1.5).

Figure A20 shows the distribution of countries in a two-dimensional map of HDI and EF with data of 2016. The size of each circle is proportional to the country´s population. The largest circle represents the world which on average has an HDI of 0,7 (i.e. reaching the threshold of high human development), but with a footprint of 1,69 Earths which is clearly unsustainable. In this context the concept of Sustainable Development (SD) is graphically represented by a quadrangle in the lower right side of the graph where HDI is high (> 0,7) and EF is low enough (< 1 Earth). Let us emphasize a relevant aspect of the challenge: the area of that quadrangle is getting smaller and smaller because its vertical dimension (EF) is measured in terms of global hectares per person. Since world´s population continues to grow, the quadrangle is getting more and more shallow.

In terms of how development is usually conceived this graph brings some surprises:

- It shows that Sustainable Development (SD) is currently an oxymoron. Countries with high levels of HDI have also high levels of EF: for HDI > 0,9, EF is never lower than 2,8 Earths although it can go up to 5 Earths;

- Conversely, many countries with EF < 1 have low levels of HDI. And when looking at time series it appears that progress in HDI is generally accompanied by substantial growth in EF: China has rapidly increased its HDI to 0,75, at the expense of having an EF of 2,2 Earths;

- European, and in particular, Nordic countries show high levels of HDI at much lower levels of EF than other rich countries (Germany has the same level of HDI as the USA but its EF is 2,97 Earths while USA´s is 4,97). But as of today European countries are not a model to replicate, their EF is very high;

- As measured by HDI-EF indicators (which is certainly reductionist but brings some insight), the best performers in terms of SD are countries in Asia and Latin America which are not usually considered as global references and whose intensity in R&I activities is below average: Philippines, Jamaica, Ecuador, Cuba and Sri Lanka combine relatively high levels of HDI with levels of EF around 1 Earth. This raises many questions about the disconnection between R&I agendas and SD and about the meaning of innovation itself.

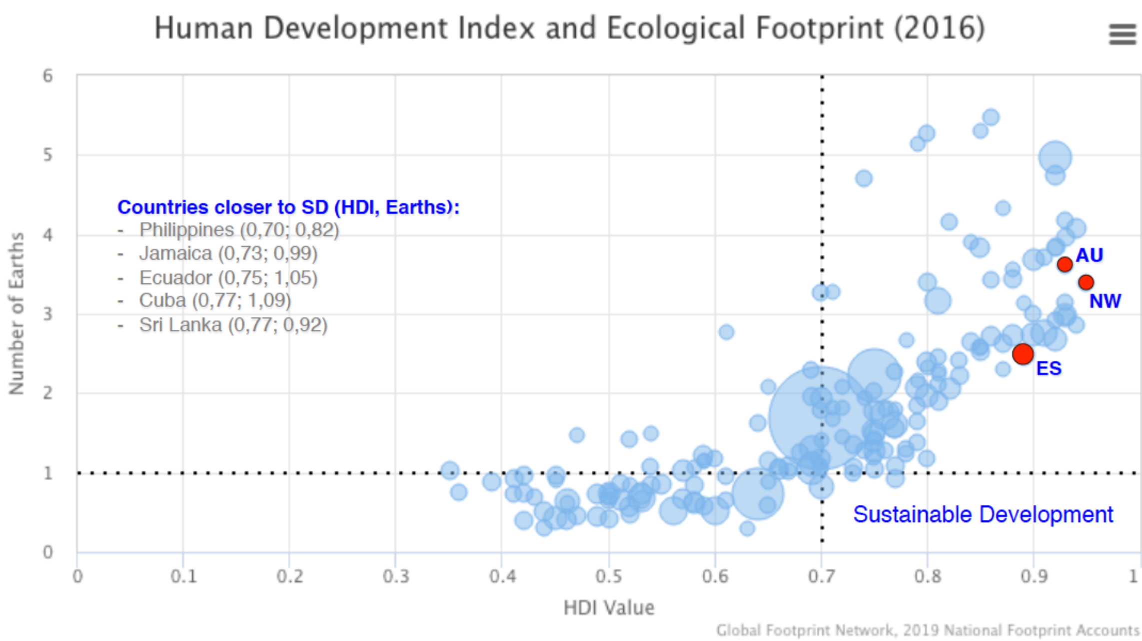

Figure A20. Human Development Index vs Ecological Footprint (source: GFN)

These observations give enough food for thought to raise questions of an unconventional type. Not only does it seem that Sustainable Development (SD) is an oxymoron, recent evolution of the indicators show that rapid progress in HDI, which is the legitimate claim of most of the world population, carries with it a substantial increase in Ecological Footprint. So, the venture towards SD which is absolutely critical for the survival of humanity, faces two challenges that we are not able to meet for now:

(1) How can we increase low levels of HDI without increasing at the same time the levels of EF?

(2) How can we decrease high levels of EF without losing established levels of HDI?

Regarding the SeeRRI territories, data of HDI and EF are not easily available at the scale required but a first approximation is to use the data of their respective countries. As shown in the graph, Austria and Norway have similar positions (HDI > 0,9, EF around 3,5 Earths) while Spain has an HDI close to 0,9 at a level of EF around 2,5 Earths. The challenge for their R&I ecosystems is to lower their territorial footprints while keeping high levels of human development.

A5. COMPLEXITY THINKING

As Henry Louis Mencken famously said around a century ago, *"for every complex problem there is a solution that is clear, simple and wrong"*. All relevant problems that humanity is facing are complex. And the same could be said of many, if not most, of those we deal with in everyday life. They are driven by multiple and interrelated causes, across multiple contexts and interdependencies. As implied by Mencken´s citation, due to the nature of complexity it is inappropriate and often tragic to address complex problems with the familiar set of mental tools, i.e. a clear diagnostic obtained by separating the problem into smaller pieces, an explicit definition of purpose and goals and a linear roadmap to reach the solution. The willingness to use a straightforward method reminds how Alexander the Great solved the intrincacy of the Gordian knot by cutting it with a stroke of his sword. Simple enough and tempting, but the multiple manifestations of complex problems are entangled with each other in such a way such that it does not work in real life. What could work, though, is to use an entirely different approach to assess both the problems and our actions. This is what this section is about.

A5.1. COMPLEXITY. COMPLEX SYSTEMS

Everyone has a specific perception of "complexity". In everyday language the word is often associated with an excess of difficulty to understand or act upon a situation: something is "complex" when it is beyond our capacity to apprehend it or when we feel we have an issue for which there will be no easy solution. And this may become an invitation either to do nothing (complexity is a common excuse not to act) or to try to simplify the issue at all costs. At the same time, since at least the 1950s a whole field of research has developed within different disciplines (but also across and beyond them), to address complexity as a characteristic of reality and an object of academic study. The analysis of complexity has produced significant literature in natural sciences and particularly in statistical physics but also in psychology, biology and life sciences at large, as well as in mathematics, philosophy and epistemology [Abraham 2002]. Social sciences and humanities have rightly claimed that complexity is at the heart of their concerns since the very beginning, while the natural sciences have been avoiding it for long, by using mechanistic techniques and abstractions to best describe and model real systems (see A2.1).

Within such a wide academic landscape related to the study of compexity, it is no surprise that we find many concrete definitions of what it is, depending on the discipline or perspective adopted, but all of them share some commonalities. Here are the most relevant characteristics:

- Complex systems are **large assemblies of autonomous actors interacting between them and with their environment in non-trivial and especially non-linear ways**. This description is applicable at many different scales, whether we talk about the assembly of cells in a body, of neurons in a brain, of members in a society (human or not), or of organizations (families, tribes, companies, cities, states, and so on) in a modern human society. The description is appropriate as well if we talk about ecosystems (see A4.2), as wholes made of many different kinds of subsystems and living beings. It also applies to Gaia [Lovelock 1979], the unofficial designation for the whole Earth system which has become an object of consideration as a self-regulating system of systems, especially in the light of the global threats of climate warming, loss of biodiversity and others produced by humans, such as the zoonosis and expansion of Covid-19;

- Not all systems are complex. A car or a plane are examples of very complicated systems, but they are designed not to be complex: we want them to be predictable. Their many pieces fit into a larger scheme, they do not have autonomous behaviors. If they show some degree of autonomy, this represents either a malfunction or a limited feature within a controlled framework;

- It also follows from the definition that **all living systems are complex**, whether at individual, group or societal levels. Individuals are themselves large assemblies of lower-scale autonomous actors: they are ecosystems on their own;

- As a consequence of the autonomy of their constituting parts, **the overall behavior of complex systems cannot be fully predicted** as for mechanistic ones. The interactions inside and outside a complex system make impossible to precisely compute its trajectory in any modelling space. The n-body problem from classical mechanics is a good entry point to the ubiquity of complexity: even considering perfect spherical bodies interacting only under the law of universal gravitation, calculating their trajectories is a problem of daunting difficulty when the number of bodies is in excess of three [Heggie 1991]. More generally, radical uncertainy, unexpected behaviors and emergent phenomena are intrinsic manifestations of complexity [Prigogine & Stengers 1997];

- Complexity is not at all equivalent to chaos, though. The modern culture of industrialized societies is so explicitly attached to predictability that the uncertain and the unexpected are more feared than welcome, whatever their character. This manifests in many different ways, one of them through conspiracy theories: if something negative happens (e.g. the crash of an airplane) it must have been the consequence of human actions. The existence of complex causal chains is simply too hard to accept and is considered as a sign of chaos. Living systems are complex, but not chaotic: they are always dynamic, in permanent evolution and open exchange of energy, resources and information with their environment, and their behavior is not fully predictable, but not erratic either;

- A distintic manifestation of complexity is emergence, the concrete realization that the whole is more than the sum of the parts: **emergent properties are features of the whole enabled by dynamic processes of interactions at high levels of energy exchange**. Their appearance is fundamentally a phenomenon of **creativity.** In the vicinity of critical points, something qualitatively new may happen, which cannot be identified in the constituting parts, but it does not necessarily happen. New forms and patterns, self-organization and ultimately auto-poeisis may appear (see A5.3).

- The main tool of analysis of complex sytems is **to look at the interactions and interdependencies within the system and with their environment**. Hence the reductionistic method of splitting a system into its parts to understand the overall behavior is not sufficient. Complexity is characterized by chains of actions and reactions and the widespread presence of feedback loops. Some of these may be direct, others are indirect and possibly happen through long chains of interaction, *"small arcs of larger circles"* [Bateson 2016]. Rather than just actions and reactions, such intricate loops could be considered as the equivalent of questions and answers leading to more questions, in an endless process of evolution (since complex systems never stay static).

These characteristics of complex systems pose significant challenges to our understanding, in particular whenever deliberate purposes are formulated to make a system evolve in a certain direction. At the highest level of leverage points as places to intervene in complex systems, Donella Meadows identified *"the power to transcend paradigms"* [Meadows 1999]. Which implies not only that a system´s behavior depends critically on the underlying paradigm from which it arises, but that our understanding can never be complete: paradigms are just contingent expressions of our level of understanding at a certain moment and hence of limited applicability. The limitations of the mechanistic framework have been challenged by the evolution of physics since the 19th century. In a process starting simultaneously across a number of different disciplines in the second half of 20th century, new paradigms of knowledge have been created to address complexity. As discussed above, common to all of them is the consideration that what characterizes complex and in particular living systems is the flow of non-trivial interdependencies between large numbers of autonomous elements (cells, living beings, organizations,...), from which myriads of networks, structures and forms can emerge in self-organized ways. Contexts and scales are not separated, they are fully intertwined and the connections, instead of being secondary, can make the difference, especially at critical points where the behaviour of a system can shift completely. This approach is substantially different from the mechanistic one: it builds on holistic perspectives rather than reductionism (see A2.2). Instead of separation as fundamental tool of analysis, it recognizes that interdependencies are at the core. Which requires replacing determinism by essential uncertainty, and questioning dualism and objectivity by recognizing the need to observe the observer and the mental frameworks in use (see A1.2 and A2.5). Last but not least, this approach also questions rationalism in that cognition processes are themselves complex: maybe reality is simply inaccessible to our conscious understanding, we just have glimpses of it (see A1.3).

How different would be our world if we had advanced more in the development of an epistemology of complex systems? This is a question we rarely ask because we take for granted that our present is the only one which could have been. But as much as our future is open, so was our past. The basic principles of the modern exploitation of solar energy were already well understood and some practical solar machines were developed in the 1850s. But humanity decided to go for fossil fuels. A century and a half later we have exhausted to a large extent their natural reserves and we face the phenomenon of global and dramatic climate change due to CO_2 and other greenhouse gas emissions at a gigantic scale. Possibly the industrial exploitation of coal, oil and gas was the easy choice, due to their high energy returns, but taking that path was also a product of our mental frameworks. We did not pay much attention to the consequences, while pollution is clearly visible when burning fossil fuels.

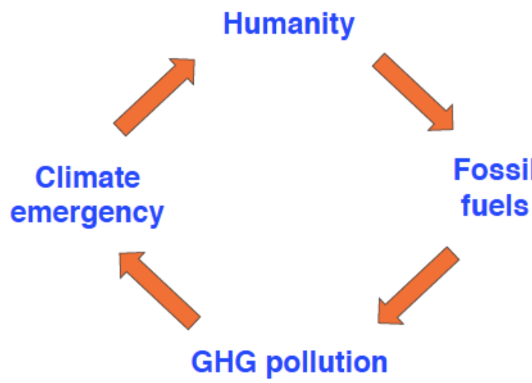

Figure A21. Climate change as the revenge of Gaia? (source: own elaboration)
GHG = Greenhouse Gases (CO2, methane, N2O, etc

Under a mechanistic framework climate change is deeemed a "collateral effect", which suggests it is secondary and can be minimized. But what actually happened is that we deliberately and systematically ignored that we live in ecosystems and that our actions to transform and exploit them to our benefit have consequences beyond the immediate outcomes we were looking for. If we take a complexity approach this is no surprise: nothing happens in isolation and interactions and interdependencies and are at the core of complex systems. From that perspective we cannot ignore the cybernetic nature of reality: feedbacks are not collateral, they are an integral part of how systems learn and change, for good or bad as far as humanity is concerned. Our reflection on climate change can be completely different if we frame it as a self-regulating response by Gaia, the whole Earth system, to reduce dramatically the number of humans in order to re-establish conditions propitious for the continuation of life at large (see figure A21). And then the question comes: can we do better than Gaia?

To answer that question we need to know if we are humble enough to recognize our limitations. Instead of aspiring to "crack the code" of a system of systems of which we are part, we would have to assume that complexity and uncertainty are foundations for the emergence of life. We would need to realize that the knowledge and the artifacts we create with the purpose of controlling complex systems are new sets of questions leading to new responses, not to "solutions". They add new layers of interactions which do not bring certainty nor predictability except at local levels. Also, that living systems are most probably impredicative (see A6.3.3): we cannot define life without referring to life itself, which makes it non-computable and controllable [Poli 2017]. Adopting such a perspective would mean a fundamental shift in our relationship with ourselves and the world, since among other things it implies that ontology, epistemology and ethics can no longer be separated between them and from us as external observers (see A1.2) [Kunneman 2010]. We are actually immersed in an endless process of mutual learning in interaction with the ecosystem of which we are part (starting with the billions of bacteria living in our body without which we cannot live). This is what the perspective of complexity tells us. It is a tool at hand that has been already here for decades and is only waiting to be developed in its applications, provided that we recognize the limitations of incumbent epistemologies.

A5.2. INTERDEPENDENCIES

Interdependency is not the opposite of independence. On the contrary, genuine independence cannot be acquired without an awareness of interdependency. Interdependency is the opposite of the fantasy of exclusion (see A1.5). It states that we cannot ignore how much our life depends on our relationships with a myriad of "others": the bacteria living in our body, the people around us, the people far from us, the intricate network of all living beings and human processes without which we simply cannot live. The crisis induced by Covid-19 has exposed very well the fragility of our highly technological societies in regard of tiny events happening on the other side of the planet. And this principle also works viceversa: the bacteria depend on us to keep alive, we are not dependent but interdependent.

The central concept of complexity thinking is that when describing a system we should give priority to the interactions, both between the autonomous parts which compose the system and with what lies beyond the system boundaries. So, potentially we should give priority to the daunting fact that everything is related to everything else. As far as explanatory purposes are concerned, this seems to create a nightmare since we cannot handle infinitely-dimensional analysis (even with modern computing tools). As described in A2.1 and A2.2 our scientific traditions have developed on the practices of separating wholes into parts and reducing dimensionality to a few variables enabling us to "control" the system under analysis. Complexity is rather the idea that the isolation of parts is not appropriate for explanatory purposes of many (if not all) of the issues which are relevant today. This is a shift in perspective: for all the details it could have, representing a system as a collection of "boxes" and a number of "arrows" between them (as in an engineering blueprint) is insufficient to capture all the richness of relationships present in a natural landscape which make possible blossoming as an emergent feature of the system (see figure A22). And let us notice that the independent existence of the flower would not exist without all the interdependencies making it possible.

Figure A22. Nature as a web of interdependencies (source: IBI)

From this new perspective, let us clarify that interdependency is more than connectedness or interactions. Connectedness is just an infrastructure layer (as in the connections between nodes of computing or telecommunications networks), it enables communications between the parts connected but it does not even suppose autonomous behaviors of the parts, much less that they depend on each other. Interaction has a stronger meaning: some kind of question-response cycles happen between the autonomous parts. But it does not necessarily describe a permanent state of mutual relationship, a meaning which is present in the word interdependency. So, complexity is not just about parts connected between each other and occasionally interacting, it reflects a dense web of permanent relationships in which mutual exchanges are the norm.

How do we practically deal with interdepencies in our conceptual frameworks? How could we not betray that strong meaning of complexity while still being able to obtain useful knowledge from our analysis? There is no detailed recipe to answer these questions and possibly there will never be. But the most important step is already taken: that which goes from ignoring or neglecting interdependencies to considering them. Hence the need to include the concept among the fundamental assumptions of SeeRRI Conceptual Framework (see D2.2.5). We do not have a recipe to take into account all interdependencies in our conscious modelling of reality, but the awareness of interdependency extends the scope and improves the quality of our questions, and it gives light to many of our blind spots as well.

A5.3. PATTERNS. SELF-ORGANIZATION. AUTOPOEISIS

Patterns of forms are abundant and very diverse in nature: symmetries, trees and fractals, spirals, meanders and vortices, waves, bubbles, tesselations, cracks, stripes, are everywhere (figure A23).Their regularity and beauty to human eyes have been a matter of wonder and speculation since the beginning of time.

Figure A23. Examples of patterns in nature (source: Wikipedia)

Since the 19th century different scientific disciplines have engaged with the explanation of patterns. In particular mathematicians (D´Arcy Thompson, Alan Turing, Benoit Mandelbrot and others) played a leading role in identifying the equations for such astonishing examples of natural geometry, which give a sort of confirmation that life is written in the language of mathematics. Now we have elements to decode the grammar of pattern language and inquire into the role of gene expression in morphogenesis. But all that and even describing with precision the processes by which the patterns are formed is not the same as understanding what makes them emerge. From a conventional perspective patterns are the application of some kind of engineered blueprint, magically contained in the seeds of living beings (in modern terms, in the DNA). But from the perspective of complexity the existence of natural forms is a manifestation of the concept of emergence, by which something qualitatively new appears out of parts which do not contain it. Forms are the outcomes of processes able to create structures, under certain circumstances (see A2.4). They require a constant and open exchange of energy, resources and information with their environment, sometimes leading to the crossing of a threshold through which creativity happens (see A6.6). Complexity thinking alludes to the concept of self-organization as the key feature for the emergence of patterns in response to conditions experienced in interaction with the environment:

> *"the capacity for self-organisation is a property of complex systems which enables them to develop or change internal structures spontaneously and adaptively in order to cope with, or manipulate, their environment"* [Cilliers 1998].

Self-organization is a label for the process by which a system adopts a certain ordered structure or pattern which arises from a different state of the system, either disordered or following another pattern. A central point is that the occurrence of self-organization requires certain conditions, in particular that enough energy is available, but not the control by any external agent, it is a spontaneous phenomenon. The concept originated at the intersection of dynamical systems theory and cybernetics in the 1940s and 1950s. The phenomenon can be reproduced artificially in very simple systems. E.g. when heating a shallow layer of fluid from below, a pattern of convection cells (aka Bénard cells) is created to accommodate the energy conveyed by the heating. In the language of dynamical systems theory the different states of a system can be represented in a certain map of phases, and the different patterns that the system can adopt are located in "attractors", certain areas of that map where the system finds a stable balance and can absorb fluctuations without changing its pattern. But if enough energy is fed into the fluctuations the system can shift from one attractor to another, from one pattern to another. And this happens with many simple and non-living systems (think of tornadoes or the street of vortices at the center of figure A23). Emergence does not require the presence of life, but of course the most outstanding manifestation of the capacity to create new patterns is the evolutionary history of **life, as the complex system par excellence**, which has produced a countless number of new forms of living beings over millions of years.

As said, dynamical systems theory identified many examples of the emergence of self-organized structures from disordered states through the amplifications of random fluctuations by positive feedback (*"order through fluctuations"* or *"order from chaos"* in the expressions of Ilya Prigogine). From an epistemological point of view that was already a break from mechanicism: in that approach, emergence happens in the vicinity of critical points in which the smallest fluctuation decides unpredictably whether the system goes one way or another, among a set of patterns in which chaos is also an option. And within that framework the role of far-from-equilibrium "dissipating structures" (see A6.4) was identified as the theoretical foundation for emergent patterns [Prigogine & Nicolis 1997]. This is the exact point of convergence between physics and biology, the studies of inanimate matter and of living beings.

Hence, in this perspective self-organization is an ubiquitous phenomenon and is not the singularity separating non-living things from living beings. That defining line may be provided by another feature, "autopoeisis", a synonym of self-creation coined in 1973 by biologists Humberto Maturana and Francisco Varela when studying biological cells. In their definition:

> *"An autopoietic machine is (...) a network of processes of production (transformation and destruction) of components which:*
> *(i) through their interactions and transformations continuously regenerate and realize the network of processes that produced them; and*
> *(ii) constitute the machine as a concrete unity in space in which the components exist by specifying the topological domain of its realization as such a network."*
> [Maturana & Varela 1980]

In other words, autopoiesis refers to the unique ability of living systems *"to continuously renew themselves and to regulate this process in such a way that the integrity of their structure is maintained. Whereas a machine is geared to the output of a specific product, a biological cell is primarily concerned with renewing itself"* [Jantsch 1980]. This characterization of living systems opened new avenues for investigation, necessarily not far from the study of feedback loops and self-referencing (see A6.2 and A6.3). While autopoiesis stresses the capacity of living systems to maintain themselves and in a way suggests that the purpose of life is no other than the persistence of life itself, this does not invalidate the appreciation that complex systems, and living systems among them, can evolve and adapt to different conditions. They do so by developing new patterns: this is the way they can learn and change [Jantsch 1980]. Such fundamental insights about complexity provide hints to go forward (see Section A6 and D2.3). Though, in a form of poetic irony, none of the above actually solves the question of why emergence happens, which may continue to be a mystery inaccessible to our understanding [Morin 2017].

A5.4. MODELLING COMPLEXITY

The expression "modelling complexity" is a good candidate to be an oxymoron. Models are reductions, simplifications of reality meant to be useful for our understanding, while complexity thinking starts from the opposite angle, by stressing how risky it is to apply reductionism and simplification (see A2.2). But rejecting completely the idea of modelling complexity would lead us to think that nothing can be consciously understood about any complex system due to the intractability of the mesh of interdependencies linking everything to everything else. Many complexity thinkers continue to work with the hypothesis that the contradiction between the act of modelling and the acceptance of complexity can be managed in a way leading to fruitful acquisition of knowledge. At least two conditions seem relevant to that purpose:

- Recognize that *"all models are wrong, some are useful"*, which almost all modelers do, but not necessarily the users of their models, who may take them for faithful representations of reality;

- Second, and even more important, recognize that uncertainty is real, not a collateral effect of the insufficiencies of our understanding which ultimately could be eliminated.

The first statement is equivalent to the recognition that we do not understand reality, we build frameworks of interpretation to make sense of our perceptions. From this perspective a fair exercise of modelling starts with making explicit the main assumptions taken in the process of building the model(s), as we do in SeeRRI by making explicit the foundations of the Conceptual Framework (see Sections 2 and 3 of D4.1).

Many natural systems (e.g. the celestial mechanics of the solar system) and almost all human-designed systems (e.g. planes and cars) are indeed deterministic, to a large extent. Classical mechanics has its domain of applicability and science has been constantly expanding the field of what can be consciously understood and predicted. But complex systems, living beings and social systems among them, fall in a different category. It is a tricky one, since as said in A5.1 they are not chaotic, their behavior is not (always) erratic. But the intention to predict their behavior in all circumstances is misleading. This is why the concept of modelling has to be fundamentally different: the purpose of the exercise is not anymore about conceptualizing complexity in order to fully understand it, hence with a view of controlling it. Understanding complexity would at least require the engagement of all our capacities, conscious and unconscious (see A6.3), which by construction is beyond the reach of our conscious mind. Rather, models of complex systems should be open-ended: they are about giving ourselves the permission to experiment complexity, expanding our capacity for perception, and engaging into processes of mutual learning. With this in mind, modelling in a way faithful to complexity might be possible if adopting the appropriate epistemology and techniques [Hoffman 2015].

As a matter of fact, the richness of the field of complexity has given birth to a multiplicity of techniques of description coming from different disciplines of mathematics and natural sciences [Abraham 2002]:

- The whole apparatus of dynamical systems theory continues to be used and may be useful for describing, in a stylized way, what happens in the vicinity of critical points (bifurcations, chaos, onset of strange attractors, etc). While this area of knowledge does not address complexity per se, it still plays a role in overcoming the classical epistemology, since models based on small sets of equations can exhibit irreversibility, emergence and other features of complex systems;

- Agent-based modelling (ABM) tools have become very popular, especially in their attempt to make social sciences more accessible to mathematical modelling (as in the field of econophysics). ABM uses sets of "autonomous" agents interacting between each other to build simulations of an overall complex system. In principle this conceptualization is the closest to the common description of all complex systems (see A5.1). Though, genuine complexity may be lost if these techniques are used as a second kind of reductionistic method: if systems are described as collections of well-defined agents, whose rules of behavior are supposed to be known and who interact between them in simplified manners, the model outcomes may be misleading;

- Complex network theory is a different approach originated in statistical physics. It is a generalization of mathematical graph theory, using large networks of nodes not randomly nor uniformly connected. It is useful to reproduce the topology and partially the behaviour of many real networks which are indeed complex systems. This domain has acquired a significant momentum in recent years, although the difficulty to model the dynamic behaviour of complex networks is a significant challenge.

Game theory is also relevant here, although it is generally applied to a relatively small number of autonomous participants, whose behaviour is frequently idealized or rationalized. ABM is somehow its generalization.

As we will see in Section A6, the challenges that complexity poses to our conscious mind may be beyond the reach of modelling, in the mathematical sense of the term, and even beyond conventional logic. Conversely, interdependencies are the core aspect of complexity, and they can be part of a framework of analysis in any discipline, without necessarily leading to a translation into some kind of mathematical modelling. What seems mandatory, though, is to have at hand a multiplicity of tools and manners of describing the intrinsically complex nature of reality.

A6. AT THE LEADING EDGE

This Section presents a number of concepts which are at the leading edge of systems research. They do not pertain to a singular discipline but have rather horizontal implications across several of them. The list presented here is not exhaustive and the concepts altogether do not yet form a consistent theory about complex systems. Though, they are relevant to understand the state-of-art in systems thinking and what lies ahead. The topics are not new, most of them were initiated decades ago, but their potential is still largely unexploited. In the context of SeeRRI they are elements of inspiration for the Conceptual Framework and especially for the ways it can be used (see Section 3 of D4.1).

A6.1. CONTEXTS. TRANSCONTEXTUAL ANALYSIS

The critique of reductionism (see A2.2) and the approach of complexity and interdependencies (see A5.1 and A5.2) lead to the conclusion that analyzing a complex system in only one context is a severe limitation that in most of cases we cannot afford. The pandemic of Covid-19 shows this in a tragic way: any relevant aspect of the consequences of the virus is linked to many others. The mechanism of zoonosis at the origin of the disease in humans is one of many instances of the same in the last decades: their higher frequency is linked to the growing destruction of natural habitats due to the pressure of human development in its industrialized phase. The rapid propagation of the virus is linked first to the high-density urbanization widespread in almost every country, and second to the high level of global mobility provided by cheap air transport. The measures of confinement have a huge depressing effect on the economy and potentially enduring social, political and cultural consequences. There is no way to look at Covid-19 without invoking many different contexts at the same time: health, science, ecology, cities, transport, industry, economy, politics, technology, education, and so on.

Transcontextual analysis takes for granted that the same happens with any complex system: its manifestations as well as its crises happen across many different contexts. And conversely, there are good chances that no complex system is actually viable in a single context, that the persistence, capacity to adapt and resilience of a complex system (see A5.1) are tributary of the multiplicity of contexts in which the system operates. Since it is hard to find a relevant object of analysis which is not linked to different contexts, it makes sense to develop specific concepts and methods for transcontextual research: this should be the norm. And yet:

> *"current institutional structures mitigate these complex issues through the protocols of attending only to what is within their specific jurisdictions. Attempts to solve health crises within the silo of the health system prove inadequate. Attempts to solve education crises within the silo of the school system are blind to the larger shifts in technology, culture, and work.*
>
> *A new approach is needed that can take into account transcontextual interdependencies that are currently being ignored."* [Bateson & Schutte 2019]

As with the focus on interdependencies (see A5.2) to which transcontextual research is closely connected, recipes for this new endeavour of inquiry do not exist yet, and maybe will never exist as such recipes. Though, the need exists for techniques offering multiple descriptions of the way an issue is nested in many contexts, which would also provide a way to get across the boundaries between the different parts of a system, transcending the mechanistic approach (see A2.1). Not least, transcontextual analysis could potentially offer insights into where reinforcing mechanisms (see A6.5) are loose enough to create opportunities for a system shift when this is needed.

To date, the most advanced attempt to create a method of inquiry for transcontextual analysis is led by the International Bateson Institute through the creation of the concept of "Warm Data", defined as *"transcontextual information about the interrelationships that integrate a complex system"*, and the process of "Warm Data Labs", especially designed to engage people into conversations on a complex issue from a transcontextual perspective. The format is carefully built upon state-of-the-art knowledge in systems thinking. It looks extremely simple to the participants and at the same times it provides a powerful tool to create the conditions for people to grasp complexity by themselves and initiate dialogues leading to a deeper understanding of interdependencies:

> *"The Warm Data Lab process creates a living kaleidoscope of conversations in which cross-contextual knowing is generated and interdependencies are illuminated. (...) It is not dependent on knowledge or skill but both increase in an atmosphere of mutual learning."* [Bateson & Schutte 2019]

A6.2. REFLEXIVITIY. HIGHER-ORDER CYBERNETICS

While our conscious mind has limitations to grasp reality in its entirety (see A1.3 to A1.5), it is capable of understanding that it has limitations. This is a quite extraordinary feature and is the foundation for reflexivity, the capacity to reflect on how we think and act. As discussed in A2.5 cybernetics consists in the realization that in most relevant issues a simple and direct causality chain cannot be identified. Behaviors of complex systems are rather governed by an interweaving of direct and feedback loops, potentially very intricate. This idea led quite naturally to the definition of higher levels of cybernetics. If at its foundational level it is the study of feedback loops in observed systems (natural or not), second- and higher-order cybernetics are the result of recursive applications of cybernetics to itself. It is a systematic inquiry into the idea that scientific knowledge is constructed by the scientific community and hence the practice of observing the observer is mandatory if we pretend to have a comprehensive perspective of understanding. If *"cybernetics is a way of looking at things and a language for expressing what one sees"* [Mead 1968], it follows that the study of how we think and how we express our ideas on reality has to be included in our study of reality. In other words:

> *"... a brain is required to write a theory of a brain. From this follows that a theory of the brain, that has any aspirations for completeness, has to account for the writing of this theory. And even more fascinating, the writer of this theory has to account for her or himself. Translated into the domain of cybernetics: the cybernetician, by entering his own domain, has to account*

for his or her own activity. Cybernetics then becomes cybernetics of cybernetics, or second-order cybernetics." [Foerster 1995]

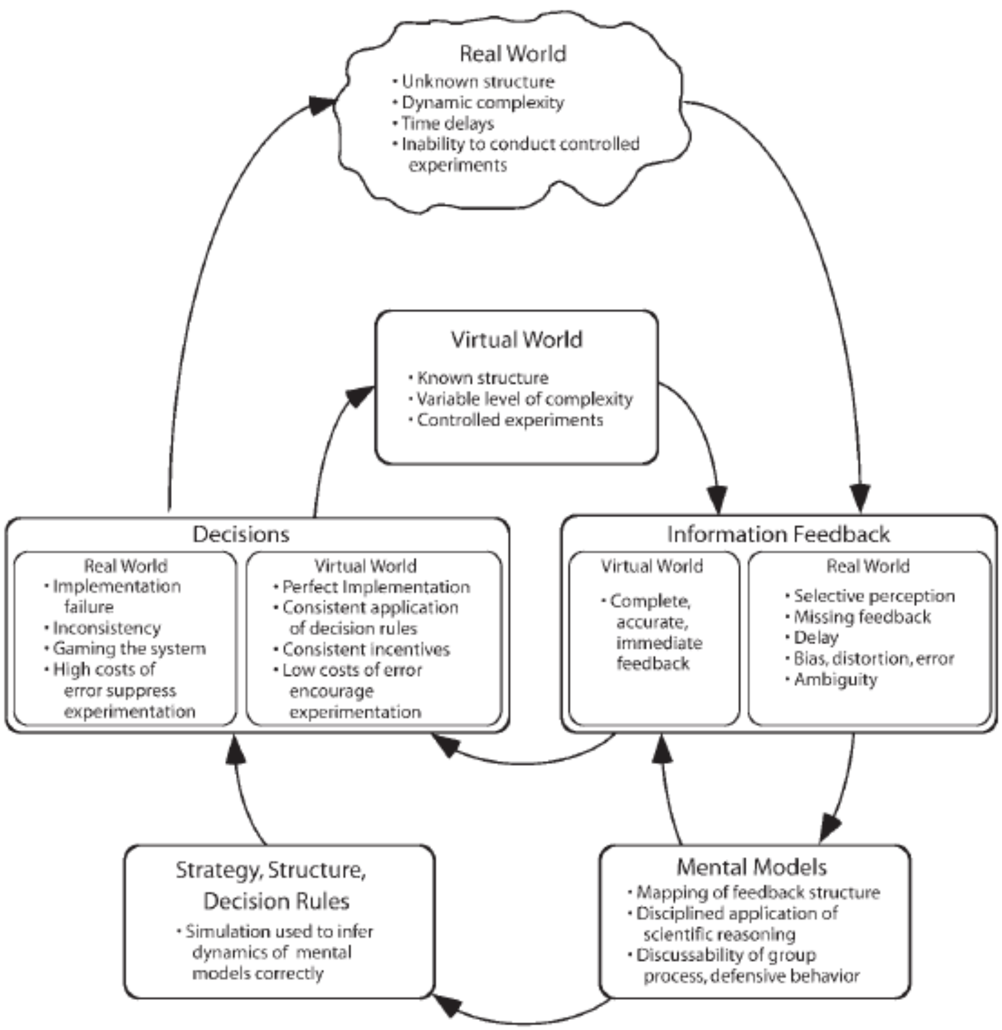

Figure A24. Idealized learning process through multiple feedback loops [Sterman 2006]

This idea is actually embedded in RRI through the principle of reflexivity. Second-order cybernetics is closely related to constructivist epistemology and to auto-poiesis (see A5.4). As a discipline it emerged in the 1960s and 1970s and continues to feed research closely linked to the exploration of complexity and complex systems. Since recursivity is recursive, third-order cybernetics has been proposed to address questions on the subjectivity of the observer (second-order) who observes the feedback loops in complex systems (first-order) [Kenny 2009]. This increasing level of sophistication could be seen as too abstract, opaque and largely sterile as far as practical applications are concerned. But the point where intellectual sophistication reconnects with reality is when analyzing and elaborating on the nature and potential of learning, and the different levels of what it means to learn (see A6.3.4).

In this respect, the use of modelling tools is increasingly considered as a way to improve and accelerate learning. It is largely facilitated by the abundance of computing facilities and data in digital form, so much so that the temptation of easily building quantitative models in computerized form may become a misleading shortcut. Modelling complexity is an oxymoron, since modelling is by essence reductionist (see A2.2 and A5.5). But we humans can hardly avoid being reductionist and as the old adage says, *"all models are wrong, some are useful".* A mission for higher-orders cybernetics is to ensure that models are built with enough epistemological consistency for them to be useful. Necessarily this means the models have to be open to a wide array of possible futures for the system under anaysis (while most models actually used are of the predictive kind, framed by a deterministic epistemology). This implies as well that modelling has to be a process of learning nested in multiple feedback loops as depicted by the graph in figure A24. In other words, learning about complex systems has to be mutual (see D2.3) [Sterman 2002 & 2006].

A6.3. FRONTIERS OF UNDERSTANDING

The challenge posed by complexity should not be underestimated. For all the limitations we can identify in the mechanistic way of thinking, there are certainly good reasons why it has been so widely adopted. Many of its characteristics described in A2.1 are much older than the Scientific Revolution, they go back to classical times. One strong reason for the adoption of mechanicism is its success in terms both of science and applications: you do not easily change an epistemology which has been so effective in its consequences (notwithstanding the assessment that can be made on these, from ethical, social or ecological points of view). But at a deeper level, our conscious mind is reductionist, it only perceives what it perceives. And this is a structural limitation on the kind of reasoning we can have. Conscious purpose provides a way of being in the world which is effective for short-term goals [Bateson 1968] and hence it is easy to see why rationalism became prevalent, as a combination of celebrating effectiveness and self-indulgence. At the same time there are also good reasons to think that we are able to do otherwise, and some thinkers promote the idea that as children we have strong capabilities to deal with complexity which are later inhibited by most of current educational frameworks [Bloom 1992]. Probably the main reason to be optimistic is our capacity to be consiously aware of the limitations of our conscious mind. This has driven many (if not all) thinkers in the history of humanity and has produced remarkable insights in the 21st century about complexity and how to deal with it without betraying its essence. This subsection presents some of these insights.

A6.3.1. Architecture of Complex Systems: Holons and Holarchies

While the concept of hierarchy has informed human epistemologies since ancient times and is embedded in mechanistic thinking (the system being above its parts), one of the realizations of complexity thinking is to question the hierarchical principle in the configuration or architecture of complex systems. The concept of "holarchy" is an attempt to propose a different type of archiecture, building upon many of the characteristics of complex systems. An holarchy is an assembly of "holons", a word used by Arthur Koestler in 1967 to designate something which is at the same time a whole and a part. The concept is an attempt to go beyond the practical impossibility of finding anything which is not of that dual nature, except maybe for the most elementary particles and the whole universe, on opposite sides of the scale. For instance, the conventional concept of hierarchy has issues in dealing with seeds and trees. What is part of what? Seeds are obviously part of a tree, but a seed contains as well a future tree. Seeds and trees form a holon. The same with the genome and the body. So, it is not only that a part at a certain level can be a whole at a lower one. Hierarchies have by definition higher and lower levels but this is no longer valid in holarchies. The bottom can be a top and the top a bottom. A fractal illustrates this absence (or ambiguity) of hierarchy: at each of its levels the fractal is self-similar, it contains the same patterns.

So, holons are connected to other holons and are at the same time wholes and parts of larger wholes. They are constantly exchanging energy, matter and information with other holons at their or different levels. Holons are dynamic entities in constant evolution, which could be described are self-organizing dissipative structures (see A5.3 and A6.4), embedded in, influencing and being influenced by larger wholes, as well as embedding, influencing and being influenced by subsystems or parts. Information flows take place between wholes and parts and horizontally. If compromised, holons may no longer recognize their interdependency with other holons and the system can break down (as happens in cancerous diseases). In this perspective, the concepts of holons and holarchies are directly connected to autopoiesis (see A5.3) and to second-order cybernetics (see A6.2).

Individual beings and their societies are holons of intermediate level, in the range of sizes going from the elementary particles to the universe (or the set of multiverses). But even this could be questioned since the two extremes of reality as we know them may be just the present limits of the reach of our mind, not the limits of reality. The holarchic perspective does not bring a final conclusion in this regard. Also, the questioning of hierarchy is connected to the concept of "rhyzome" coined by Gilles Deleuze and Félix Guattari in the 1970s to designate frameworks of interpretation escaping the need to recognize a hierarchy. For instance, the relationship between the orchid and the wasp is a horizontal, trans-species connection giving birth to a multiplicity (a unity that is at the same time multiple). The concepts of holons and holarchies can be applied not only to biological systems but as well to cultural ones, by considering that the basic units carrying meaning and reproducing themselves as agents of cultural propagation, known as "memes" in the metaphor developed by Richard Dawkins, could be described as holons.

A6.3.2. Communication: Double Binds, Schismogenesis

Since interactions and interdependencies are at the core of the perspective of complexity it makes all the sense that communication becomes a central topic in the study of complex systems. Research on communication was initiated in the 1920s under the impulse of the Bell Laboratories as a mainly technical field devoted to the quantification, storage and communication of information. World War II defined cryptography as the central challenge of the field, with many brilliant minds involved in it (e.g. Alan Turing). In 1948 Claude Shannon initiated a mathematical theory of communication, focused on the optimal encoding of information for its transmission, using statistical tools developed among others by Norbert Wiener, one of the co-initiators of the field of cybernetics. For all the value developed in those studies, a wider perspective of communication was missing, which could only be brought by thinkers in the domains of anthropology, psychology and semiotics. These disciplines were looking beyond explicit verbal communication and the technical means to facilitate it, into the manifold reality of communication as it happens among humans and animals. Emphasis is put on the large amount of implicit knowledge culturally framing even the simplest form of explicit communication, as well as the possibilities of paradoxes and misalignments derived from that, and the individual and social consequences this could have.

As relevant examples in terms of the analysis of behavior of complex systems, let us just mention here the concepts of "double bind" and "schismogenesis", both crafted and popularized by Gregory Bateson in the 1950s and the 1930s respectively, and still in development as of today. A double bind is the creation of a dilemma when an individual or a group receives contradictory injunctions at different levels of communication [Bateson 1972]. Responding to one injunction creates a failure in responding to the other, so the overall response is always wrong. In many situations the dilemma is not easy to confront, so the indiviual or the group cannot resolve it nor get out of the situation. The injunctions may be perceived as real but not necessarily explicit nor simultaneous, so the identification of the dilemma is not straightforward. For instance the messages can be conveyed by tone of voice or body language and hence harder to deal with in an explicit way. They can come from different levels of authority, e.g. students at school receiving messages from their teachers which they perceive as contradictory with what they hear at home or in the media. If double binds are frequent events in ongoing relationships with high levels of commitment, they can lead to emotional distress and eventually nurture serious mental diseases (Bateson first analyzed it in the context of schizophrenia). Also, double binds are often a form, deliberate or not, of coercion without explicit violence, potentially leading to learned helplessness, a situation in which an individual or a group perceives a loss of capacity to be in control of its context and to achieve goals. The confusion created by double binds makes difficult both to respond and to resist.

The expression "double bind" has also been used by Norbert Elias in the context of international relations. He designates as such situations in which two rival states both portray the other as the agressor and develop highly emotive responses to whatever actions are taken on the other side, leading to dangerous processes of mutual distrust and fear, and potentially of destructive escalation [Elias 1987]. The Cuban Missile Crisis between the USA and the USSR in october 1962 is the perfect example: it lasted 13 days during which the world got very close to full-scale nuclear war. And it was a collective double bind in tha Batesonian sense, since both parts were inclined at the same time to act against the other to avoid giving an impression of weakness and not to act due to the high levels of mutually assured destruction a nuclear war would entail. The vicious circle created by communication was ultimately solved by creating additional circuits of communication which made possible the de-escalation.

This example of double bind is connected to another concept developed by Gregory Bateson, "schismogenesis", as the process of creation of division between individuals or groups of the same culture. Bateson described it as *"a process of differentiation in the norms of individual behaviour resulting from cumulative interaction between individuals".* Schismogenesis is the result of cycles of interactions where responses are mutually aggravating, either in a complementary way, one part being aggressive and the other submissive (as happens in social class struggle) or in a symmetrical manner, where both parts are equally aggressive (as in an arms race between rival states).

From the perspective of the complexity, neither double bind and schismogenesis can be understood without taking into account the fundamental interdependency between parts involved, and in both cases emergent phenomena can be outcomes of the cycles of interaction, provided these are intense enough. As seen, what emerges is not necessarily positive (mental disease or social conflict), but it could be so if the complexity of the process is understood.

A6.3.3. Challenges in Reasoning: Abduction, Logical Types, Impredicativity

For good reasons we value immensely our capacities for logical reasoning. But complexity challenges them. In an intellectual landscape framed by the confidence that science can slowly but surely uncover the mysteries of the world, complexity brings in back unpredictability and uncertainty as essential characteristics of reality. And it reminds us that we might not be getting closer to complete the map of knowledge, whatever we do the unknowable might remain, especially in the form of what we do not know that we ignore. Socrates is famously reported to say *"The more I know, the more I realize I know nothing"*. From the perspective of complexity it could be more appropriate to say **"the more we know, the less we know"** because new knowledge also brings new levels of interactions with reality and hence new complexity and unpredictability. For instance, the consideration of emergence as a substantial phenomenon, not a mere consequence deducible from other characteristics, enables us to know more about the conditions under which emergence can take place but it does not resolve its mistery. We cannot develop a deterministic theory about emergence [Morin 2017]. And there are chances that knowing about emergence makes emerge new phenomena, hence enlarging the domain of reality beyond our knowledge.

It is no surprise then that thinkers trying to deal with complexity have been experimenting with tools beyond the realm of conventional reasoning. One of them is "abductive logic", a complement to other types of logic, such as deductive and inductive reasoning. Abductive inference starts with an observation or set of observations and looks for the simplest and most likely inference from the observations. The process does not positively prove the inference and it is based on a logical fallacy: by observing many white swans we might conclude that all swans are white, which is not true but provides a good first approximation. As discussed in previous sections, in complex systems things are not necessarily black or white, true or false: our conscious access to reality is limited, so we have to deal with ambiguity and paradoxes (f.e. holons are at the same time parts and wholes, see A6.3.1). This is why abductive logic can be useful to provide interesting insights. It is often used nowadays to give priors, i.e. starting points for machine learning algorithms in AI.

In practical terms life is full of phenomena defying a basic version of rationalistic logic, and paradoxes are easily created. For instance we cannot decide if the proposition *"propositions can be either true or* *false"* is applicable to itself. It cannot be false since otherwise it would not be a general law about propositions, but then it is denying itself. Bertand Russell proposed a way out to solve this kind of paradoxes by developing a theory of "logical types". According to it, the proposition above is a meta-proposition, a proposition about the rest of propositions, and hence does not pertain to the same class as all ordinary propositions. In that framing self-referential statements are neither true or false but meaningless. So, in order to deal with self-reference and prevent the emergence of logic antinomies and paradoxes, Russell establishes the idea that different logical levels or types exist: a class is of a logical type higher than its members and to avoid confusion no class can contain itself as a member. Life and language are actually full of this kind of situations in which circularity leads to confusion, if using ordinary logic. Communication pathologies such as double binds (see A6.3.2) typically happen because the contradictory injunctions come from domains located at different logical levels. Higher-orders cybernetics (see A6.2) addresses as well this issue. The theory of logical types tries to avoid self-references, but what if these are ubiquitous and a fundamental aspect of life that lies beyond our usual way of reasoning?

The term "impredicative" was also coined by Bertrand Russell to designate any object whose definition is self-referential, that cannot be defined without referring to itself. Again, the challenge (from a conventional epistemology) is in the paradoxes which can easily be created: "Russell´s Paradox" is about the set of all sets that do not contain themselves. Such a set cannot exist: if it would exist, one can ask if it contains itself or not: if it does then by definition it should not, and if it does not then by definition it should. The instrument of logical types can help avoiding paradoxes, but what if impredicativity is indeed ubiquitous? Centuries of work in many (if not all) scientific disciplines have been built upon the idea that most objects of analysis are predicative: they can be defined by referring to other objects that have been previously defined. And hence knowledge accumulates by piling up objects´ definitions and properties referring to previously defined objects. In that perspective it is taken for granted that impredicative objects are exceptions, just nice games of mathematical logic without serious consequences on the endeavour of science. But then it happens that:

> *"Organisms generate the very parts they are made of; minds produce the psychological processes they are based on; societies produce the roles or patterns of actions they are made of."* [Poli 2013]

And more generally the most important things are indeed impredicative. Who can define love without referring to itself? The same with life. Self-references, self-organization, auto-poiesis (see A5.3) are manifestations of the impredicative nature of reality. And the consideration of impredicativity may be only relevant because we were forcing things to be otherwise. If most of relevant things are impredicative, this ceases to be an issue in itself. The issue lies in the limitations of our incumbent epistemology in dealing with real-world systems, which are complex (and hence impredicative). But that being an issue means also a great opportunity to open new avenues for continuing the adventure of knowledge. Complexity is not a further improvement after mechanicism, it is where we should have started from the very beginning.

A6.3.4. Levels of Learning

In order to derive practical consequences of our exploration, a fundamental question is how epistemology is related to the process of learning. Is learning driven by complexity different from learning driven by more conventional views? Since learning is the acquisition of new values, knowledge and behaviors, it makes sense to match the changes in our views about the kind of knowledge we can acquire and how to frame our perceptions, with changes in our views about learning. This area of research has been nurtured by systems thinking and cybernetics and is especially intense in the domain of organizational learning, probably because private corporations facilitate more incentives for practical reasons (their own improvement as purpose-driven organizations) than other types of organizations (including educational institutions, which should be the most interested in the topic). In any case, in correspondence with an approach of reality based on the concepts of complexity, the idea emerged that there are different types or levels of learning, corresponding to different levels of abstraction, as presented in table A3:

Learning IV	'would be *change in Learning III*, but probably does not occur in any adult living organism on this earth'.
Learning III	'is *change in the process of Learning II*, e.g. a corrective change in the system of *sets* of alternatives from which choice is made'.
Learning II	'is *change in the process of Learning I*, e.g. a corrective change in the set of alternatives from which choice is made, or it is a change in how the sequence of experience is punctuated'.
Learning I	'is *change in specificity of response* by correction of errors of choice within a set of alternatives'.
Learning 0	'is characterised by *specificity of response*, which—right or wrong—is not subject to correction'.

Table A3. Levels of Learning in Bateson´s perspective [Tosey et al 2011]

Learning 0 could actually be qualified as "not learning" since behavior is not corrected whatever the result. But in a certain sense it derives from the learning that stability of behaviour is important. Learning I is about the ability to try different responses within an established set and learn from errors. Higher levels correspond to increasingly higher levels of abstraction in what has to be changed to obtain an appropriate response in a particular situation. This stratification imagined by Gregory Bateson [Bateson 1972] is closely linked to the theory of logical types of Bertrand Russell (see A6.3.3), and similar schemes have been developed by others [Argyris & Schön 1978]. The identification of different levels can be misinterpreted, though. They do not correspond to a hierarchy or to a pathway of capacities to be progressively acquired, and much less to a segmentation of humans according to their invididual capacities to reach one level or another. This elaboration on learning modes should not be used as an argument for ex-post justification of social stratification. Learning modes can happen simultaneously and there are good reasons to think that the range of capacities shared by all children is in this respect are much richer than mechanistic and performance-driven views of education would suggest [Bloom 1992]. Also, according to Gregory Bateson, the higher the level the more the non-conscious mind and the totality of experience are engaged: he considered that Learning III level is beyond language and hence cannot be pursued in an instrumental way. Moreover, the kind of epistemological shift that Learning III represents is probably always associated to a deep transformation of the self (not far from what an epiphany means in religious language), with all the risks it conveys of getting trapped in some kind of mental disease.

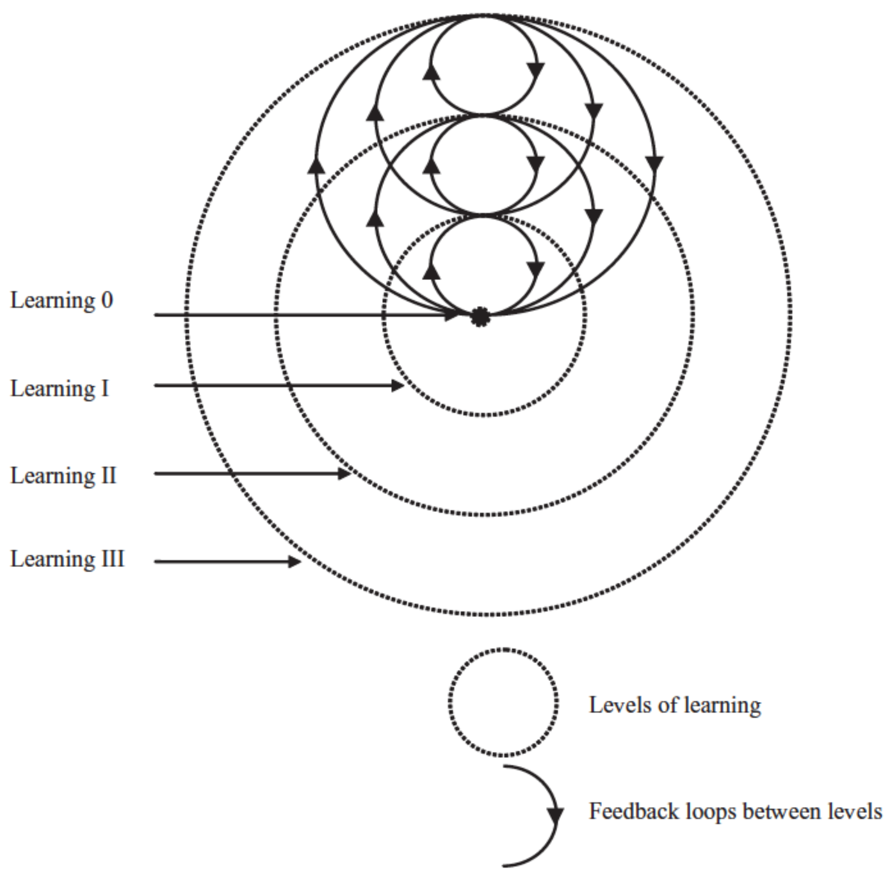

Figure A25. A recursive view of Levels of Learning [Tosey et al 2011]

Figure A25 is a graphical representation of how the different levels are nested in multiple feedback loops and as said can (or must) happen simultaneously. Again, circularity is key, which of course should not be a surprise: learning without engaging into feedback loops would simply not be possible. Which is ironic if one thinks that the dominant epistemology framing our society as well as our educational systems has been mostly ignoring feedback loops: no surprise then when we realize that education has been mostly devoted to teach fixed sets of responses rather than to the process of learning.

Last but not least, what is implied by this perspective of learning at different levels is that dealing with complexity requires enlarging the sets of responses that can be tried (and the sets of sets, and so on) in constant interaction with whatever we are trying to learn about. Hence the idea that mutual learning (see D2.3) is the best (or maybe the only possible) approach for that purpose.

A6.3.5. Automated Knowledge Discovery

While the purpose of this Section is not to have an outlook on what is happening at the leading edge of all scientific disciplines, it makes sense to bring in an assessment of the current trends in automated knowledge discovery through "machine learning", a set of techniques widely used in the domain of "Artificial Intelligence" (AI), an extremely active area of research and applications. While the aspiration to build artifacts capable of intelligent behaviors has been part of human cultures since centuries, scientific attempts to develop AI started in the 1950s, with a summer workshop celebrated at Dartmouth College in 1956 as the founding event. Nowadays machine learning follows a different approach from those which were tried until the 1990s. Instead of codifying and implementing ex-ante rules for what could be an "intelligent" behavior of a machine, one of the current approaches tries to infer rules of behavior from data (this is why abductive reasoning is important in this context, see A6.3.3).

In the explicit intention to reproduce how our brain works, machine learning builds upon "artificial neural networks" and learns from the data, by observing them in a systematic way and discerning statistical regularities in large historical datasets to anticipate future events, supposed to follow the same patterns. In 2016 machine learning defeated champion Lee Se-dol at playing go (a much more complex game than chess) and Google Translate services were overhauled with a substantial improvements of results. Current progress in AI is fed by a combination of factors: the advancements in algorithmics (a branch of computer science derived from the mathematical concept of algorithm), the availability of exponentially growing amounts of data due to the expansion of internet and digitalization and the increasing capacities of hardware and software to process huge datasets. In a way this is the paradise of computer science made true: much more data are available, as well as much more capacity to analyze them.

From the perspective of complexity and all what has been discussed in previous sections, a reflection on what "intelligence" means seems mandatory. Intelligence is most probably another example of an impredicative concept (see A6.3.3), impossible to define without referring to itself, but let us assume that we define it as the manner in which we humans deal with the information we get from ourselves and the environment in order to make the best possible choices of action. In this sense, since digitalization starts basically as a new way of collecting, processing and exchanging data in massive quantities, it seems natural to consider its role in the improvement of our societal intelligence by expanding our capacities of processing information. But this straightforward association is built upon some assumptions which deserve to be made explicit:

- In terms of information, "more" leads inevitably to "better",

- Better information leads to better (more intelligent) decisions,

- More intelligent decisions lead to better futures.

Although one would be tempted to agree with all of them, from a philosophical point of view these assumptions require more scrutiny. To the very least, they invoke a quality of "better" which looks very differently if considered at the individual, community, national or global levels. That quality pertains to the non-technical domain of public debate, societal choices and historical contingencies. Recent successes of AI make us think it is helpful to discover new knowledge up to now inaccessible to humans. This would consequently lead to increase our capacity to take "better" or "right" decisions in every aspect of human and social life. Although it has limitations, machine learning has shown new capacities to detect patterns in historical data which would not be identified otherwise. Building upon that technical evidence the public framing of AI in recent years went directly into the anticipation of major contributions to social transformations, as part of an unstoppable so-called 4th industrial revolution to which human societies should simply adapt, and that will be for the better [Diamandis & Kotler 2012]. Part of the promise is to fully automate many (all?) human tasks and by doing so to improve process productivity and efficiency at a massive scale, and then it would be to humans to decide what to do with the huge benefits generated in that way. But it seems worth analyzing again some of the assumptions which are implicit in that bold jump of imagination between technical achievements and social consequences. Here are three of them:

- The extraordinary growth in accessible data and computing infrastructures, combined with progress in data science and machine learning algorithmics, makes it possible to infer meaningful correlations and patterns from existing data related to phenomena of interest;

- These patterns can be useful to develop different levels of analysis of the observed phenomena: description (what happened?), diagnostics (why did it happen?), prediction (what will happen?) and even prescription (how to make happen what we want?);

- With the progress of AI the reliability in the mentioned levels of analysis makes or will make possible not only the automation of repeatable tasks but to transfer the responsibility of taking decisions to AI artifacts, with no or very little human supervision (e.g. in autonomous vehicles).

Again, these assumptions sound plausible. But again they contain many concepts which are not technical, and making them explicit is a good step forward to understand what can go wrong with our expectations of AI and more generally of technological innovation (see A3.1). We currently live in a moment where expectations are very high. The digital industry has been excellent in the production of discourse and positive metaphors, such as "smart cities" or the naming of AI itself. In recent years AI has been heavily publicized by interested parties and the media (not by the scientific community) as a "silver bullet" to help us addressing all the pressing challenges that humanity faces. The current conversation is about developing some kind of "general purpose intelligence" and expanding its field of applications. In a not too distant future, the discourse goes, we would able to create a "super-intelligence", "something a billion times smarter than the smartest human", as Anthony Lewandosky puts it . And then we could subcontract the solution of all our challenges to the robots, because even top-level decision-taking positions (such as the presidency of the USA) would be better fulfilled by robots. That is, the world would be better managed by AI artifacts because they will have better information and a better understanding of hidden causalities, and also have the added benefit of being free from human emotions. This vision is not a minor bet for the future of humanity.

Epistemology and the concept of blind spots are again relevant here (see A1.2 and A1.5). Regarding AI in its modern form based on machine learning, some blind spots are intrinsic to the underlying techniques, others are related to the extrapolation of actual achievements to influence public debates. While machine learning facilitates the acquisition of knowledge which could not be produced by other human means, as said above there is not a necessary equivalence between more and better information. Data processed by machine learning algorithms are reflections of context-dependent phenomena but by construction only parts of the interdependencies relevant to the phenomena are actually present in the data. It could not be otherwise: the first step in AI is to consider that reality can be effectively represented by a finite (even if large) set of quantified data, as if the information contained in administrative forms could faithfully represent the whole from which it is extracted. We know that creating forms, however detailed they are, is always an exercise in making reality fit into a set of squared boxes. To a certain extent this is an effective procedure: reducing the potentially infinite number of influencing factors in any phenomenon of interest facilitates a practical understanding and AI enables us to deal with a higher number of factors. Though, increasing the quantity of data may help in improving our models but it does not change the nature of modelling as a reductionist exercise.

The aphorism points to a key question: "useful" always refers to a certain purpose, often not explicit (and this is where blindness comes in). We can recognize that recommendation algorithms are useful to identify books, movies or music close to our taste, which in turn is useful for the digital sites using them to increase their sales. This is a typical case in which AI leads to a certain type of control: influencing customers to buy more of what we guess they like. But the underlying categorization of customers, even if much richer than the traditional ones used in marketing, is still a categorization: it is just a model, not the complex reality of the people who at a certain moment behave as customers. Using all sorts of categorizations facilitated by machine learning is still a reduction of our complex and interdependent lives. Since current pattern recognition requires huge amounts of data from many different cases to be effective, it is necessarily based on decontextualizing information and discarding interdependencies, in other words on denying the uniqueness of each of our lived experiences. So, again, reductionism can be helpful for specific purposes and to obtain a local controllability of the object of analysis (e.g. consumers´ behavior), but it has a price and it can be heavy: as Alfred Korzybski rightly said*,"the map is not the territory"*.

Also, machine learning is probabilistic by nature, it provides statistical regularities but rarely a reasoning nor an explanation of why the regularities exist. While current research is addressing the issue of explanability of results, this is still a challenging problem which makes transfer of responsibility from humans to AI artifacts especially sensitive. Although many technical developments are undergoing to address the limitations of current AI algorithms, *"there is good reason to believe that, compared to human brains, the Deep Neural Networks (used by AI) are brittle, inefficient, and myopic"* [Watson 2019]. They need a large number of cases to learn (while a kid can learn what a dog is almost in one shot, and for all dog breeds) and can be easily cheated by adversarial algorithms. They identify patterns but do not know what makes sense. And explanability is not anywhere near. More importantly, since AI predictions and prescriptions are grounded on the extrapolation of identified patterns, their reliability depends on the stability of those patterns and hence we can expect better results when AI is applied to deterministic phenomena (or close to). But this is a pretty stringent requirement if one pretends to use AI for every aspect of life and aspire that it can make the world more controllable. Life as a whole is non deterministic, its patterns are changing all the time and constant interactions between cognitive agents (humans and non-humans) produce new, unexpected and unpredictable phenomena (see A5.1 to A5.3). This is the mark of complexity, and it is actually increased by the addition of AI-based artifacts as new cognitive agents in new layers of interactions. Hence AI will not help in controlling the world at large: it may be useful for controllability in local contexts and scales but overall it increases complexity and reduces predictability. This is a fundamental limitation as far as the techno-utopia of a world better managed by AI is concerned. At the same time, it also opens concrete avenues for reframing the development and use of AI techniques for purposes of Responsible Research and Innovation in the context of our societal challenges.

A6.4. NON-EQUILIBRIUM THERMODYNAMICS

Thermodynamics is the branch of physics dealing with heat and temperature and with energy and its ability to be used for work (in the sense of the term in physics, i.e. as the product of force and displacement). Non-equilibrium thermodynamics is the study of systems which are not in and do not tend to a state of thermodynamic equilibrium. From non-mechanistic perspectives non-equilibrium is much more important than equilibrium, since it is considered as the normal state of all relevant systems, especially living ones, while equilibrium is more the exception than the norm or even just a mental experiment.

This consideration of the irrelevance of equilibrium is extremely important, also for its implications in disciplines far from physics: e.g. equilibrium is at the core of mainstream theories in economics, while economic processes and systems are by construction dynamic and far from equilibrium. There is an epistemological issue in developing whole theories of practical importance on an hypothesis which is inconsistent with or not relevant in reality. There may be a number of reasons why this has happened, though. One is the prevalence of classical mechanics, for which equilibrium is indeed a relevant concept, in the historical development of modern science and its applications since the 17th century. Also, our perception of the persistence of living systems (starting with our bodies and our identity as individuals) has probably misled us in thinking that equilibrium is much more ubiquitous than it is. We are ourselves systems far from equilibrium, performing at the same time the maintenance of our functions and their evolution thanks to a continuous exchange of energy, materials and information with our environment. But the perception of the overall stability of the complex systems that we are is misleading in this respect: stability is dynamic and very different from equilibrium. Stable and static are different things. A third reason for the prevalence of equilibrium as object of analysis is simply inertia: once a whole discipline has been built around that concept, it is difficult to transform it. The fact itself that we use the term "non-equilibrium" is revealing: equilibrium is still at the center of the predicate, while we should be using "dynamic" for the normal state of all systems and "static" for the exceptional situation in which they are not dynamic.

The mentioned reasons contribute to what is a blind spot at the core of many scientific disciplines. And this is one of the reasons why non-equilibrium thermodynamics is so important. The other main reason is that it is an area of convergence which conciliates physics and biology, the living with the non-living. Thermodynamics states that the total energy of an isolated system remains constant (conservation of energy) while its quality degradates continuously over time (entropy being a measure of that degradation). Thermodynamic equilibrium is the ultimate point of that process, in which entropy is maximal and no work can be obtained from the system. Living systems can only reach thermodynamic equlibrium by dying (another good reason not to put equilibrium at the center of scientific endeavours). In other words, thermodynamics can only address living systems by considering non-equilibrium and actually far-from-equilibrium situations. This area of study has been extremely fruitful in the last decades, leading to the creation of new concepts in an attempt to explain:

- the essential irreversibility of natural and human processes;

- how ordered structures can emerge out of chaos ("dissipative structures");

- the onset of self-organization, which happens when a system shifts by taking one of the branches emerging from the bifurcation in the vicinity of a critical point [Prigogine & Nicolis 1977];

- the role of threshold conditions and entropy production in that process of bifurcation towards the emergence of something qualitatively new [Jantsch 1980];

- the essential uncertainty which characterizes the future behaviour of all complex systems [Prigogine & Stengers 1997];

- the process of "autopoiesis" (see A5.4) by which a system is able to maintain and reproduce itself, a characteristic of all living systems.

All these concepts have nurtured an intense dialogue between thermodynamics and biology, and in particular with the domain of ecology (see A4.1). Among others, this connection has been useful to show why the blindness of economics to ecological issues is founded on its ignorance of thermodynamics, and hence could be addressed in a scientific manner [Georgescu-Roegen 1971, Mirovski 1991].

Why is all this relevant in the context of SeeRRI? It is not because we are going to use non-equilibrium thermodynamics as such in our analysis of R&I processes in territorial contexts. But this branch of physics provides a number of powerful concepts and criteria which could be used by analogy (not only as metaphors) in the reflections on what can make territorial R&I ecosystems self-sustainable through a perspective of RRI. In particular, the ideas on the sustainability of RRI processes (see D3.2) are largely inspired in non-equilibrium thermodynamics and its implications (see A6.5).

A6.5. CRITERIA FOR SELF-SUSTAINING PROCESSES

As discussed in A2.4, process philosophy is a fundamental element of our approach and hence of SeeRRI Conceptual Framework (see D2.1). From that perspective, in the analysis of the evolution of any kind of system a central element is to understand which processes grow and which are declining. Moreover, when one intends to promote a deliberate direction of evolution, a first and critical step is to understand which are the conditions required for the favourable processes to grow and be sustainable over time. Defining such a set of conditions is an ongoing topic of research but we can use at least the following commonalities [Jantsch 1980]:

- Openness: processes have to be able to exchange energy, resources and information with their environment in order to persist, evolve and adapt while keeping their own identity and singularity;

- Energy: processes are not static, they are embodied in far-from-equilibrium dynamic entities, one of whose characteristics is to capture large flows of energy from their environment;

- Auto-catalysis: to keep the processes alive and thriving, their outcomes have to reinforce certain steps of the processes themselves.

We take for granted that these three criteria can be applied to any process at any level. The analysis of social processes cannot proceed in exactly the same way as for physical and biological processes. But we consider that the concepts used to define the three criteria above can be transposed as more than just metaphors to our purpose, i.e. the analysis of processes in R&I ecosystems. The concept of "energy" is not identical to that used in physics, but it can easily be particularized in the context of SeeRRI. Human processes also need to capture energy from their environment, and this has a number of concrete forms which can be practically assessed: a non-exhaustive list would include financial revenues, time and efforts committed by volunteering individuals (not by employees since in that case the net amount of "energy" is supposed to be zero), new talent attracted, attention captured from society at large, and so on. While this characterization of "social energy" would actually open a new domain of research which goes beyond the purposes of SeeRRI, it can be used in practical ways in the context of the project.

More broadly, the evolution and health of human processes and the structures (organizations) to which they give birth can be analyzed in the light provided by this type of analysis. If for whatever reason an organization becomes too closed in upon itself or fails in retaining the flow of energy it receives from its environment, it is empirically known that it will soon start to decline. But the most important criterion is that of auto-catalysis because it ensures the exponential nature of process growth when the right conditions are met. An obvious example of auto-catalysis is the demographic mechanism: the more children are born in a generation, the faster the population will grow. Another example is the self-reinforcing nature of the appropriation of economic benefits by the company producing them: the more profitable it is, the faster it can grow if the benefits are reinvested in the company operations.

On the other hand, processes do not unfold in purely abstract ways, they take place in spaces of many different kinds (physical, virtual, conceptual, etc) and they are related to different contexts: think of the simple act of feeding ourselves and how it is connected to biology, health, culture, technology, economy, society, politics and so on. Of course, in this radical "process philosophy" one could get lost among intertwining processes at multiple levels, each of them conditioned by multiple contexts. This is why transcontextual analysis needs to be developed (see A6.1). But a substantial part of the SeeRRI approach consists in selecting on which processes, at which levels, and considered within which contexts, it makes sense to focus our analysis, as far as the main goal of promoting RRI is concerned. For the purpose of SeeRRI a specific selection of contexts is made to make the Conceptual Framework operational (see D2.2.5). Overall the importance of looking at processes is a crucial element: as far as a large-scale transformation of R&I ecosystems is concerned, we make the hypothesis that the difference will ultimately be made by RRI-based processes growing and populating the domain of R&I activities faster than those not built upon the RRI approach.

A6.6. THE MISTERY OF LIFE: EMERGENCE FROM EMERGENCY

"Life is a game whose purpose is to discover the rules, which rules are always changing and always undiscoverable" Gregory Bateson (*"Metalogue: About Games and Being Serious"*)

This subsection closes the Thesaurus part of this Report. A large number of concepts from different disciplines have been explored to shed light, from the best of systems and complexity thinking, on many intellectual and practical challenges of relevance for humanity. Ultimately that exercise is meant to bring light to the challenge of promoting self-sustaining R&I ecosystems informed by the philosophy and policy of RRI in territorial contexts. The ways these concepts are used to build the SeeRRI Conceptual Framework and to apply it are described in Sections 2 and 3 of D4.1.

The internal roadmap of this Report is connected to the roadmap of human civilizations in the last three centuries, a phase of our history which has been characterized by an extraordinary expansion in all aspects of human life (population, occupation of the Earth, technical capacities and knowledge), as well as in the destruction of other humans, living beings and natural habitats alike. It remains to be seen if the "noosphere" anticipated by Vernadsky and Teilhard de Chardin, now tagged as the "Anthropocene", is an era of equitable human wellbeing at peace with a healthy biosphere (the vision invoked a century ago when naming the noosphere) or the shortest of all geological eras. Whatever our degree of confidence in our capacity to understand and to create artifacts, it could be that we humans are finally not able to avoid the combination of existential threats we have created, not so much endangering life at large but mainly ourselves.

If we really intend to prevent the collapse of modern civilizations, we should better revisit our capacity for humility, instead of continuing the blind celebration of our past achievements while we drive faster and faster towards the abyss. Previous sections (and the sources on which they are based) have shown that our conscious mind has a limited access to reality, and this has probably no solution. **We do not understand reality, we just build frameworks of interpretation through which we try to**

explain what we perceive of reality. And this process can be utterly misleading, it leaves many blind spots (see A1.5). But at least we know we have blind spots, and that makes a big difference.

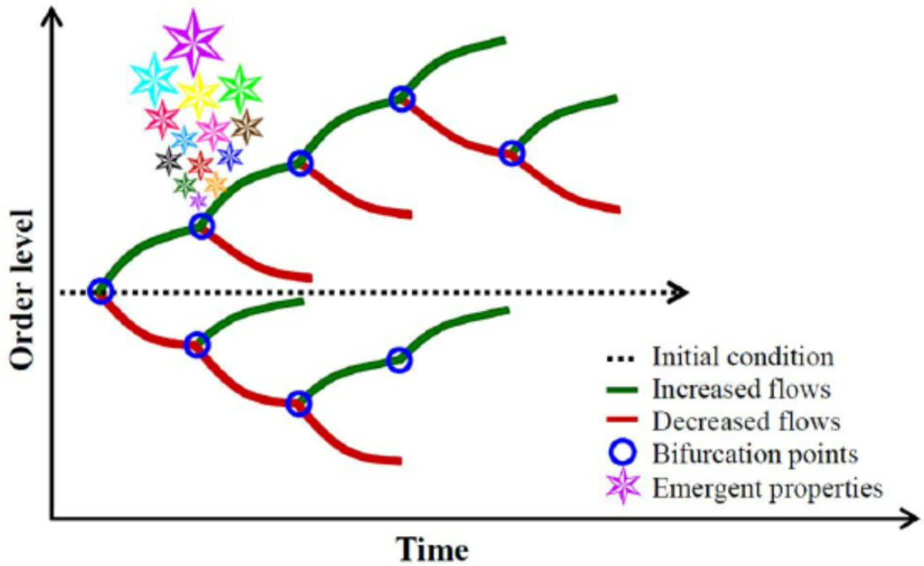

Figure A26. Bifurcations in dynamical systems [Source: ResearchGate]

Most probably, as the citation above by Gregory Bateson and recent reflections by Edgar Morin suggest, we will never complete our understanding of the mystery of life [Morin 2017]. But through decades (actually centuries) of thinking about complexity, we have hints on some basic facts. An important one is that critical points are ubiquitous: all kinds of systems go through situations in which they can shift from one state to a completely different one, in complex processes of "bifurcation" (see a simplified representation of the concept in figure A26), which are characteristic of a very wide range of dynamical systems, including living ones. To follow the description by Erich Jantsch:

> *"**The essential feature** is the internal reinforcement of fluctuations (by autocatalysis) which eventually **drives the system over an instability threshold into a new structure**. In the transition, it is not the macroscopic averages which play their usual role, but the internal amplification and the breakthrough of fluctuations which started very small. In other words, the **principle of creative individuality** wins over the collective principle in this innovative phase. (...) However, it is not predetermined which structure will come into being. At each level of autopoietic experience, **a new version of macroscopic indeterminacy comes into play**. The future evolution of such a system cannot be predicted in an absolute way; it resembles a decision tree with truly free decision at each branching point."* [Jantsch 1980]

There is little doubt that this framework to interpret how the emergence of new behaviors happens in complex systems is applicable to biopoeisis, the original emergence of life on Earth from inanimate matter, as well as to subsequent events in the history of evolution such as the Cambrian explosion of

541 million of years ago, when the diversity of forms of life expanded very rapidly, so as to start resembling that of today. Life has been evolving and innovating during millions of years and taking into account the results, we should recognize that in comparison our capacity to innovate is quite limited (another aspect of the required humility): nature is able to produce a countless number of viable forms of life by using very few materials and producing no waste. 160 years after the insights of Darwin and Russel Wallace and going away from a widespread interpretation in reductionist terms, time has also come to understand that competition may play a very limited role in the evolution of life on Earth [Weizsäcker et al 2018].

As announced by many thinkers, we humans are now at a turning point in the history of civilization: it is time to bifurcate, to **emerge into a substantially different type of organization from the many emergencies in which we are involved**. Another knowledge we have acquired is that emergence does not happen through a smooth and painless transition, it unfolds in critical situations through painful emergencies during which the outcomes are not predictable nor guaranteed in any way. As repeatedly said, there is no other way to go through the process of emergence than by climbing a steep ladder of mutual learning. But we do not build completely from scratch. In a humble manner, we can use some ideas derived from a careful observation of natural intelligence, expressed e.g. as follows, in the form of 10 rules governing how all life works [Gorissen 2020]:

> *"there is no taking without giving;*
>
> *it takes an ecosystem to sustain an ecosystem;*
>
> *interdependency rules; nothing occurs in isolation;*
>
> *the byproducts generated are as fundamental to evolution as the innovations themselves;*
>
> *diversity, decentralization, and redundancy build resilience; monocultures and monopolies build brittleness;*
>
> *keystone species create favorable conditions; conditions that enable regeneration from the bottom-up;*
>
> *it is the avoidance of competition that drives evolution;*
>
> *invest in the health of others to ensure your own;*
>
> *leave it better than you found it;*
>
> *never take all."*

As Leen Gorissen concludes, *"the nature of the future and the future of nature are interdependent".*

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