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OPINION PAPER

No Sustainability Without Regeneration: A Manifesto from an Entrepreneurial Viewpoint

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Abstract

Sustainability means perpetuating the living conditions on our planet. All living conditions, no one excluded, are produced by ecosystem services, including the environmental stability and the physiological equilibrium that protect our health. Nature perpetuates these ecosystem services by spontaneously regenerating the biosphere. A corollary of these enunciations is that there cannot be sustainability without regeneration or, in other words, that sustainability is just regeneration. It is, therefore, urgent to address and quantify the regenerative capacity of the planet, which is the difference between the net primary production and human extraction of resources. Natural capital depletion is also a cause of poverty and inequality, due to its impacts on food security and on the economy in general. A second corollary of our diagnosis is that, due to its multisystem complexity—economic, social and environmental—sustainability must be managed with a systemic approach; in other words, it cannot be managed from a reductionist angle. The paper is structured in sections that address the transition from Holocene to *Anthropocene* and its implications, i.e. the fact that a clear-cut distinction between nature and culture no longer holds, while humans need to support the regeneration of lost natural capital. Then a section follows that addresses the close links between the social crisis (increasing inequalities) and the environmental crisis, and explains why any attempt to regenerate lost ecosystem services requires also action to fight inequalities and improve well-being of all. An analysis of the deep drivers of the environmental and social crisis is followed by a conceptual discussion of regeneration and its relationships with sustainability. This leads to the formulation of some proposals for a regenerative commitment of society, including in particular entrepreneurs and scientists, in the form of a Manifesto with five policy recommendations.

Keywords Sustainability · Regeneration · Ecosystem services · Inequalities · HANPP

1 Introduction

The whole planet has become the "evolutionary niche" of humans, a definition of *Anthropocene*. Other species are niche constructors and ecosystem engineers (e.g., beavers) but none has transformed the whole Earth into their niche (Meneganzin et al. 2020; Odling-Smee et al. 2003). In doing so, the human species has overexploited natural resources: as a consequence, the planet is in a disequilibrium state, with a potential non-linear trajectory leading to collapse if the exceedance of the "planetary boundaries" continues to worsen. One of the key disequilibria—among several—is between extraction of CO_2 from the geosphere and the ability of the terrestrial and ocean systems to absorb it (Richardson et al. 2023).

The environmental crisis is a social crisis as well. If policy-making does not understand this, it is inevitable that social inequalities will increase. Degradation of social relationships, lack of trust in institutions and a collapse of democracy might occur in the near future (Peñuelas and Nogué 2023).

Given the extensive loss of natural capital that is happening and will likely worsen, some semantic considerations are necessary. First, the word "sustainability", which is the expression of a steady state of a system (tending to perpetuate itself over generations), has become obsolete and unrealistic in a world that has lost its equilibrium (Søgaard Jørgensen et al. 2023). The word "mitigation" is more realistic but also somehow limited. Mitigation is only a partial and

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insufficient line of action for conservation, in a context in which resources are rapidly depleted. From a practical point of view, what would be really needed is *restoration* of the lost resources, considering also the strong interdependencies between the various planetary boundaries (e.g., the nitrogen cycle, biodiversity, ocean acidification, climate, etc.) (Kopittke et al. 2021; Persson et al. 2022; Elhacham et al. 2020; Cantera et al. 2022). Regeneration is the biological process responsible for conservation or restoration, depending on whether the amount of biomass which is regenerated is equal or higher than the depleted mass. Since a return to the *Holocene* is impossible, as we argue later (see also Søgaard Jørgensen et al. 2023; Hamilton 2017), the question is whether we will be able to safeguard a regenerative capacity allowing sustainability or, in the correct perspective, to rebalance our ecological footprint in relation to planetary biocapacity. Sustainability should be interpreted as the maintenance of life on the planet, which is entirely the product of ecosystem services. The regenerative capacity is given by the primary production of the biosphere minus the human ecological footprint, where the first is limited by the Earth's surface: this means that the only way to increase the regenerative capacity is to decrease the human ecological footprint.

2 Aim of the Paper

The aim of this paper is to suggest that a systemic approach is the only way to address the catastrophic environmental crisis in front of us, and this requires an organized commitment of private business, including investors, the civil society and governments. The paper has been written by an industrialist and chemist (A.I.) and a public health researcher (P.V.) and is the expression of a network of industries and investors (see Appendix).

Different segments of society seem to be currently separate in silos**,** for example those that characterize scientific disciplines, that evolved in a way that encourages extreme specialization including in language. But silos also affect all the other stakeholders of a transformative process. On the contrary, a new network of scientists, environmental associations, enterprises, investors, and policy-makers can create the critical mass not only for the provision of correct information on actions to perform, but also enthusiasm and motivation, *showing that change is possible.*

In addition to the systemic approach that we advocate for, we also explain the reasons why sustainability can only be achieved with regeneration of the lost natural capital, and propose a roadmap to that end.

3 What Happened Between the *Holocene* and *Anthropocene*

The environmental conditions which have been deteriorated are reflected in the planetary boundaries framework (Rockstrom et al. 2009). There are a few questions we need to answer to diagnose the severity of the crisis:

(i) If the boundaries crossing is reversible or irreversible
(ii) Which are the risks caused by crossing the boundaries
(iii) The possible mitigation actions to contain the risks
(iv) The possible restoration actions in case of boundaries being crossed with *reversible* consequences
(v) The possible alternatives in case of boundaries being crossed with *irreversible* consequences.

As a matter of fact, *Holocene* provided the conditions for *Anthropocene;* in fact, there is continuity between the two, though the *Anthropocene* represents a dramatic acceleration (Steffen et al. 2015; Head et al. 2022; McNeill and Engelke 2014). The geosphere supplies a large stock of mineral resources, and the biosphere provides a continuous production of *ecosystem services*, which, among others, produce resources for life like oxygen, water, food and other raw materials. Ecosystem services are usually grouped into four broad categories: *provisioning*, such as food and water; *regulating*, such as the control of climate; *supporting*, such as oxygen production and other natural cycles like nitrogen; and *cultural*, including well-being (https://seea.un.org/sites/seea.un.org/files/lg23_cices_v5.1_final_revised_guidance_03-10-2017.pdf). They are produced thanks to biodiversity in the natural capital, and the interactions within the biosphere and between the biosphere and the geosphere. Therefore, their supply is a function of the biocapacity of ecosystems, and the resulting primary production (flora) and secondary production (fauna). Together with the abiotic part of nature, ecosystem services also contribute to the biogeochemical cycles, which are responsible for homeostatic regulation of the living conditions on our planet. As natural humid ecosystems like forests express the highest biocapacity, the supply of ecosystem services can only decrease proportionally to the loss of those ecosystems caused by anthropization and climate change. As the *Holocene* conditions have been compromised by overexploitation, the question is whether in the new *Anthropocene* conditions the biosphere can still provide enough ecosystem services to ensure a stable environment and resources for growth.

To give an idea of the quantities involved, according to an estimate human appropriation of net primary production is approximately 15.6 Pg C/yr (Pg = petagrams, or 10^{15} g), 23.8% of potential net primary productivity, of which about 53% is contributed by harvest, 40% by land-use-induced productivity changes, and 7% by human-induced fires (Haberl et al. 2007; Costanza et al. 2014; Paudel et al. 2021). The economic estimate for the total global ecosystem services in 2011 was $145 trillion/yr. It has been estimated that the loss of ecoservices from 1997 to 2011 due to land use change was $4.3–20.2 trillion/yr, depending on which unit values are used (Krausmann et al 2013).

4 The Environmental Crisis is a Social Crisis

It is well established that the environmental crisis amplifies social inequalities and vice versa (Vineis and Fecht 2018). All forms of environmental degradation have a greater impact on the poorest sectors of the population. COVID-19 has shown that even a pandemic has more severe health consequences for the poor (Courtin and Vineis 2021). The concept of "syndemic" has been coined to describe how diseases cluster (i.e. multiple diseases affect the same individuals or groups), interacting biologically and multiplying their overall burden. In the case of COVID-19, low-income, ethnic-minority groups were more likely to be exposed to the virus, to succumb to it, and were less able (in multi-generational, overcrowded housing) to protect their families from the disease. Also, low-income populations are more impacted by diseases related to premature ageing (e.g., diabetes, hypertension, high cholesterol). The very same concepts apply to the effects of environmental degradation at large: landfill and dumping sites, polluting industries, air pollution and water pollution are more intense or closer to low-income neighborhoods, and so is the intake of unhealthy food (Vineis et al. 2016).

The intertwining of social inequalities on a global scale and environmental degradation (the "extractive" economy) has a long history (Piketty 2022). In fact, the Western industrialization was made possible by a mobilization of resources and workforce on a planetary scale, what Thomas Piketty has called the great "colonial experiment".

What can we expect for the future? We are already observing that floods, wildfires, drought (and its effects like malnutrition) and climate-related infectious diseases like malaria affect disproportionately more the poor, both within and between countries. This is likely to get worse in the next years, and will induce mistrust in the institutions in broad sectors of the population. The "too little too late" scenario, as described by the Club of Rome (https://www.clubofrome.org/impact-hubs/reframing-economics/earth4all-book-launch/), is the one currently chosen by most if not all States, but it will reveal itself a boomerang when the social crisis will worsen.

5 Drivers of the Crisis

We describe here some of the main, multiple drivers of the current crisis, that are at the roots of the obstacles that policy-making encounters in addressing it.

5.1 Unnatural Ecological Footprint, Demographic Broken Rules

Anthropic activities overall are responsible for a per capita energy consumption that is much higher than that corresponding to sheer food calories (Ritchie 2021; http://chartsbin.com/view/1150). If we combine the effect of overpopulation and excessive anthropic energy consumption, the human ecological footprint can be estimated to be thousands of times higher than our commensals and tens of thousands higher than any species of comparable body mass.

The human civilization has outnumbered every species with a comparable body mass by a factor of more than 10,000. As a benchmark, rats, as human commensals, are the only mammal with a population whose size is estimated to be similar to that of *Homo sapiens,* but their body mass is ~ 300 times smaller. In November 2022 we have reached 8 billion individuals. In 1922 we were approximately 1.9 billion; in 1822 we were around 1.05 billion, and in 1722 more or less 730 million (https://ourworldindata.org/population-growth-over-time#:~:text=After%201800%2C%20this%20changed%20fundamentally,number%20of%20people%20ever%20born). This is a supra-exponential growth: 0.36% compound annual growth rate (cagr) three centuries ago, 0.6% cagr two centuries ago, 1.45% cagr one century ago. This cannot be sustained in any imaginable scenario. Fortunately, human population growth is now slowing, and could slow markedly in the 21st century, even peak and begin to decline under the proper socioeconomic conditions.

5.2 Development Model and Damage to the Natural Capital

As we have seen, the development model that started during the industrial revolution is *extractive and linear*. Extraction on a large scale started during the imperialistic era in those that are now low-income countries, and it was based on both extraction of natural resources and mechanization. Economic activities deplete natural resources, both from the biosphere and the geosphere, for the production of goods and services that, in turn, produce sharply rising flows of pollution and waste. Energy consumption rose from 12,000 terawatts (TW) in 1900 to 28,000 TW in 1950 (cagr 1.7%), 122,000 TW in 2000 (cagr 3%), and 173,000 TW in 2019 (cagr 1.8%) (https://ourworldindata.org/global-energy-200-years). Most of the energy sources are fossil, with an increasing proportion compared to renewable energy, from 70% in 1950 to 77% in 2000 and 79% in 2019 (https://ourworldindata.org/global-energy-200-years). Total food consumption went from ca. 3.15 trillion kilocalories in 1969 to ca. 8.5 trillion kilocalories in 2019 (cagr 2%). Soil used for agriculture reached 45% of habitable land at detriment of forests, which now represent only 38% of the terrestrial surface (https://ourworldindata.org/global-land-for-agriculture). One century ago, land used for agriculture was ca. 25% of habitable land and two centuries ago it was half of that.

5.3 Natural Capital is Finite, Both in the Biosphere and in the Geosphere

A balance between the human ecological footprint and nature's biocapacity can be reached only if consumption does not exceed the *net primary production and secondary production*. This is a necessary but not sufficient condition because the human appropriation prevents enriching the biosphere and regenerating the portion which is lost. Agricultural productivity did increase in the last century thanks to improved agronomical practices (crop selection and breeding, fertilizers), at detriment of other ecosystem services. However, today climate change, pollution, and biodiversity loss are leveling off further productivity increases. Moreover, arable land per person halved in the last 60 years, from 0.36 ha/person to 0.18 and cannot be increased due to saturation of suitable land (7.8 billion ha suitable land of which 2.3 marginally suitable, 4.6 moderately suitable and 0.86 highly suitable; cultivated land 5.1 billion ha) (https://data.worldbank.org/indicator/AG.LND.ARBL.HA.PC).

At present, we consume in a manner that rapidly and severely depletes natural capital while endangering medium-to long-term food security and necessary ecosystem services continuity.

6 Sustainability or Regeneration?

The concepts of sustainability and of regeneration are different. Sustainability is a condition related to the ability of the human species to safely co-exist with other species on Earth over a long time, and is commonly described according to the three dimensions (or pillars) of environmental, economic, and social sustainability. An important complement is the definition of sustainability proposed by Gro Harlem Brundtland, which is at the basis of the 1987 document "Our Common Future" by the *World Commission on Environment and Development (*WCED), where sustainability is divided in two parts, (i) 'meeting the present needs…' and (ii) '…without compromising the future generations'.

Regeneration is a more recent term derived from biology: it is the process enabling a cell, tissue, or organism to recover from damage, thereby contributing to their ecosystem conservation (https://www.nigms.nih.gov/education/fact-sheets/Pages/regeneration.aspx). Regeneration, therefore, refers to ecosystems replacing or restoring what has been consumed (e.g., harvested). These principles, as far as the regeneration of the natural capital is concerned, have been put forward in particular by the Ellen MacArthur Foundation (https://www.ellenmacarthurfoundation.org/regenerate-nature). As a matter of fact, perpetuating living conditions on planet Earth is made possible only by the regeneration of nature, and this helps understanding why *sustainability is a condition which cannot be reached without regeneration*. The regenerative capacity is however limited, by the Earth surface, climate (biocapacity) and anthropization (ecological footprint, i.e. it is hindered by natural resources depletion—especially land and water—as well as pollution).

Regeneration needs to be considered in the context of the *Anthropocene*; this is a concept that was coined within the natural sciences but has been criticized, in particular by philosophers of science, for lack of clarity (Santana 2019). The *Anthropocene* implies that we have to abandon the nature-culture dichotomy, that has been typical of *Holocene*. In the current world, "nature" has been incorporated into culture, meant as the transformative capacity of humans. A second feature of the *Anthropocene* is its non-linear development: we face a planetary system characterized by strong interconnections created by humans and superimposed to those existing in nature, in a constantly unstable equilibrium if not frank disequilibrium.

Our question is what are the policies that are necessary in an era in which reaching a new state of equilibrium for the planet has become an integral part of politics, not an external condition like in the *Holocene*.

In the *Anthropocene*, the environment, the society and the economy are not separate, but require joint consideration (Steffen et al 2015). These are all hyper-complex and intertwined systems, mutually producing cause–effect relationships which transfer the unsustainability of one system to the others. The consequent overall dynamic is one of a unified 'eco-socio-economic' metasystem, in which technology, education, business, consumption, climate, biodiversity and other elements concur to people's health, security, prosperity, as well as to natural resource depletion, pollution, and loss of resilience. This explains why any attempt to manage one issue at a time, with a reductionist approach, cannot trigger spontaneous regeneration, and is therefore doomed to fail, as demonstrated by the enormous delay in finding effective remedies to the climate and environmental crisis.

As others (Lövbrand and Mobjörk, 2021) have noted, the conception based on sustainability has tended to treat nature as though it were something external to human society, rather than something in which humans are now the driving force (see also Dasgupta 2021). According to Dryzek and Pickering (2019), concepts such as "preservation," "conservation," and "restoration" are *Holocene* concepts, overlooking the union of nature and human intervention, i.e. "*cultured nature*" that is typical of the *Anthropocene*. The thesis is that solutions cannot aim to go back to the *Holocene*: the idea of restoring the stability of natural systems existing before the transition from *Holocene* to *Anthropocene* is somehow misleading. To be sure, going back to the *Holocene* has never been an explicit and conscious aspiration; however, the target (i.e. the type of equilibrium we are aiming at with "sustainability") is never clearly specified.

One key term in Dryzek and Pickering's book on "The politics of *Anthropocene*" (2019) is "path dependency", a concept and practice that was typical of the *Holocene*, and that is what we try to abandon. A path dependency arises when an initial technological choice narrows the downstream options, making them part of a somewhat inescapable pathway. Path dependency means that technology has been conceived and developed in such a way that all reparative actions find an obstacle in the in-built entrenchment of each technology. For example, transportation has been closely tied to fossil fuel-based engines and to a number of ensuing products and services (typically, highways), that in the logic of such transportation system became inescapable and created a network of dependencies. This is obviously true for other productive sectors, including food. Technology in its different aspects has become a Moloch that is very difficult to amend partially or deconstruct. Path dependencies mean that social sciences and humanities are regularly lagging behind, following an already entrenched technological path. This is also at the roots of the difficult relationships between information, knowledge, and policymaking, since the options offered to society follow the technological path dependencies of the current media. We should not underestimate the importance of the digital revolution in communication, i.e. a revolution in technology that was *followed* by a revolution in social relationships and societal organization. Any discourse on planetary boundaries cannot ignore this huge phenomenon in its positive aspects (rapid circulation of scientific and technical solutions, rapid circulation of ideas on how society should organize itself …) and negative aspects (polarization, fragmentation, information overload, echo chambers, etc.). This is another example of a strong path dependency, that may be enormously amplified by Artificial Intelligence.

Overcoming path dependencies and technocratic solutions implies referring to a set of values independent of technologies, i.e. a *vision of society*. One of our claims is that we cannot address the current challenges without social sciences, i.e. we need to overcome the traditional separation of natural and social sciences and forge a strong alliance between them. Technology itself is usually considered in association with science, but it comes in fact from the conjunction of science and social values. Technology is deeply culture-laden and value-laden, but this is not usually understood or acknowledged (Ravetz 2003). Whereas we can develop powerful technological tools to tackle the planetary crisis, similar tools in social sciences and humanities are not as developed, and this creates a dangerous imbalance. Such an imbalance became clear with the COVID-19 epidemic (Saltelli et al 2020). Scientific information and technology are not sufficient: *a vision of society is needed*.

7 Challenging the Definition of Regeneration

From the preceding considerations it follows (a) that sustainability is quite a challenging concept, since damage to the planet is too vast, and (b) that a regenerative model is needed to rebalance the ecological footprint with biocapacity. *In fact, we claim that regeneration is the only realistic approach to sustainability.* We are aware that there are constraints and limitations in this reasoning, since going back to the *Holocene* is impossible. A condition of complete self-sufficiency of nature is not attainable with the current extractive model, since there is now an inextricable intersection between the "human planetary niche" and underlying natural phenomena. Therefore, we propose a temporary definition of regeneration (and regenerative society): *'creating new conditions for planetary self-sufficiency, i.e. the ability to regenerate depleted natural resources by rebalancing biocapacity and ecological footprint' (within the expected size of human population).* The fact that the human species is itself part of nature is not a conceptual problem, since our species is the one that most evidently used intentionality, self-consciousness, and agency to create its planetary niche. Empowerment of nature's self-sufficiency, however, does not mean aiming at the same equilibrium that was typical of pre-*Anthropocene* centuries, and can be reached only thanks to scientific, technological, social, economic, and political breakthroughs. The alternative is the slippery slope of progressive depletion of resources, as epitomized by the "Earth Overshoot Day" concept.

8 A Manifesto from a Network of Entrepreneurs

The regeneration of natural capital is the only possible process to reach sustainability. Therefore, the transition to a new regenerative development model is needed, and it is vital to create all the possible conditions which make it happen.

The requirements of the regenerative model are:

1. To address the main causes of unsustainability, starting from the social and economic ones, with the systemic approach of complex systems. Environmental and social issues, including health, are strictly interconnected.
2. To reduce the ecological footprint at a level which is lower or equal to the biocapacity, through circular economy, *industrial symbiosis* and nature conservation.
3. To acknowledge that planetary and demographic changes hinder exclusively nature-based solutions, that need to be enabled by science and technology, according to the couple 'nature & culture'.
4. To steer economic development in parallel and synergistically with the social and the environmental development.

The regenerative society framework is a virtuous circle combining people's search of well-being, meant as health and happiness, with companies' transition to circular economy, meant as minimum natural resources depletion and pollution eradication, with the aim of boosting spontaneous regeneration of the biosphere (biomass and biodiversity) (Figs. 1 and 2). This virtuous circle must be nurtured with people engagement through education and communication about relevant aspects like regenerative agriculture, correct nutrition, circularity, industrial symbiosis, energy efficiency, carbon-free energy, ecosystem services, etc., together with companies' systemic approach.

9 Policy Recommendations

Policy recommendations originating from the preceding considerations can be ordered according to priorities.

9.1 Well-Being and Equality

An overarching theme in any planetary regenerative action is social inequalities. The environmental crisis is doomed to exacerbate inequalities and poverty, via mechanisms such as conflicts and climate migration. The risk is that of non-linear negative synergies, with trends that reinforce each other in a downward spiral. A big concern is about *loss of trust in institutions* that could facilitate—together with a misguided AI revolution—a collapse of democracy (Peñuelas and Nogué, 2023).

Poverty is related to population growth: in liberal societies, we cannot promote policies aimed at limiting population growth without addressing poverty and the social gradient. There is evidence of an inverse relationship between poverty alleviation and demographic increase, which is one of the reasons why it is recommended to approach all

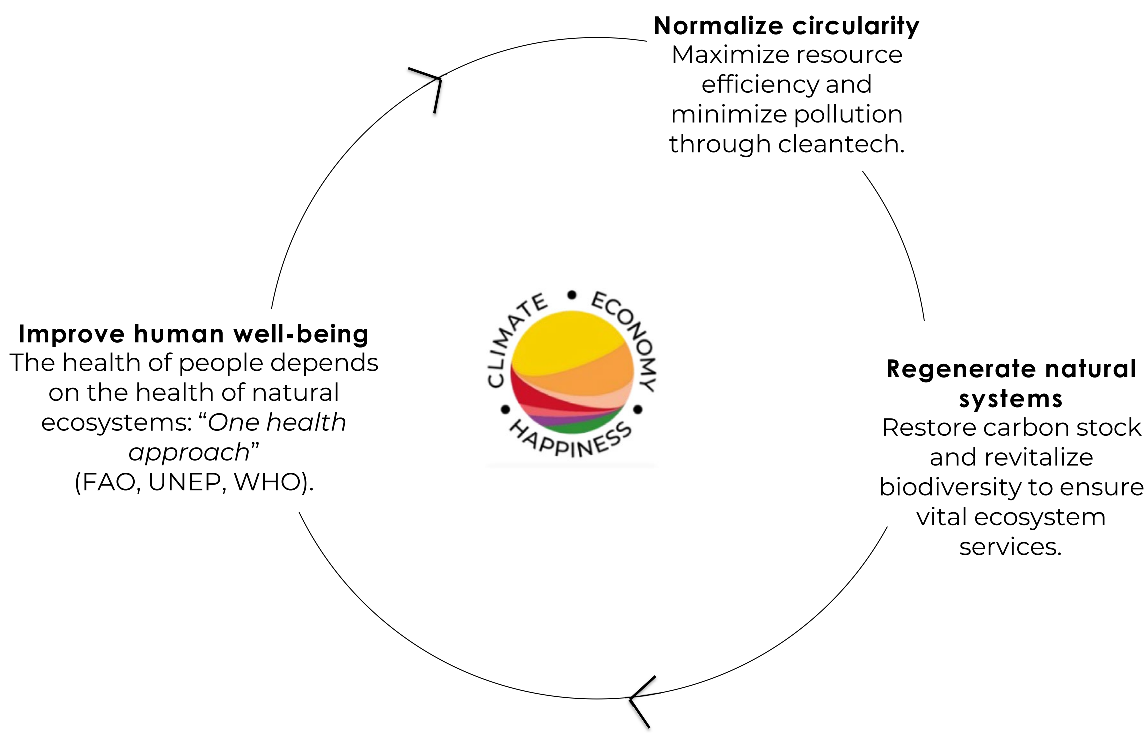

Fig. 1 The regenerative model: a virtuous cycle. The figure represents the general approach of the RSF, with a circular relationship between the three pillars of well-being (including fighting inequalities), promotion of circularity through minimizing pollution and maximizing efficiency, and regeneration of natural systems

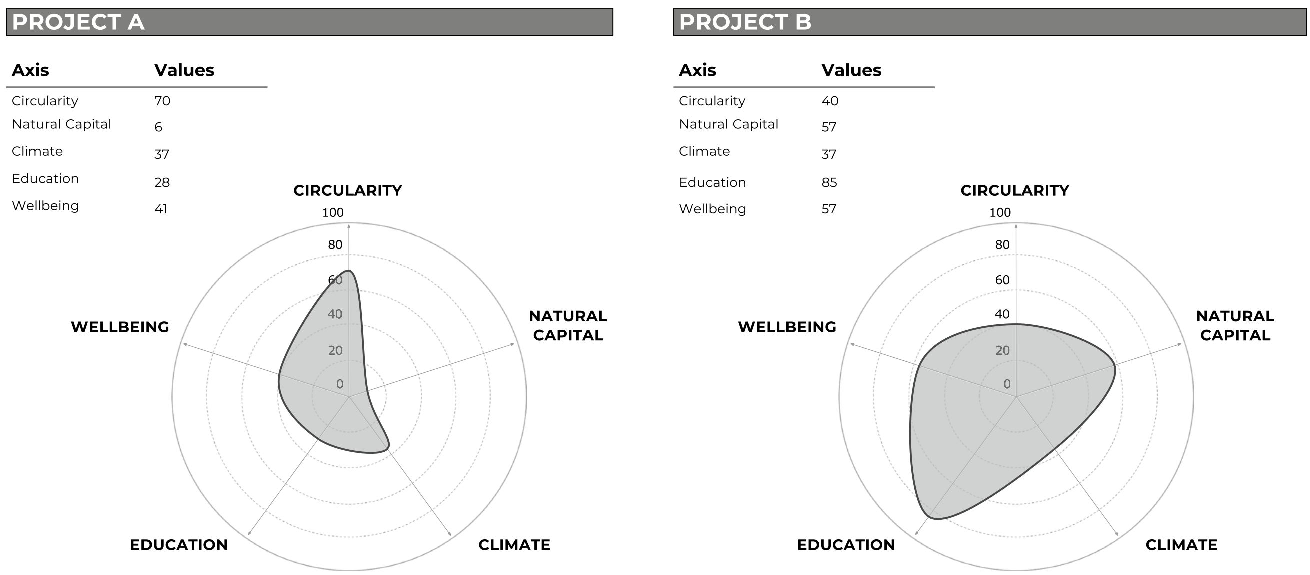

Fig. 2 Pilot regenerative profiles: two examples. The figure describes two examples that illustrate the output of the analysis with the regeneration measurement framework. The evaluation is based on five axes: circularity, natural capital, climate, education and well-being. For each axis we have introduced detailed parameters and a score between 0 and 10. Zero means abiding by the laws, ten means attainment of full regenerative potential. The scores are then represented by areas in the graph. Company A (Project A) exerts intense recycling activities and reaches a very high score for circularity thanks to the practice of "industrial symbiosis" (waste from one activity is used as raw material in another activity or by another company). Company B (Project B) leads a pilot project involved in regenerative agricultural practices aimed at scientific research and dissemination activities. This project scored particularly high for education thanks to its scientific publications and significant educational activities with other companies in the sector. The visualization of scores into areas allows a direct comparison across projects or companies, and across time

sustainability strategies starting from poverty eradication and prosperity. This is achieved only with women's freedom, empowerment, and social inclusiveness, and should be part of corporate responsibility.

In general, well-being (including health, happiness, education, security, etc.) should be at the center of the agenda since it creates a positive synergy with the health of the planet. This is well expressed by the 2030 Agenda, that stresses the interdependence of environmental and social issues (including population health), but the latter aspect has been largely overlooked by policy-making so far (Griggs et al 2013).

9.2 Economy, Private Sector, Finances

The economy is the engine of the transition to the regenerative model. Economy ethics is about creating value with goodness; or, more explicitly, without wrongdoing. Society should agree upon the general principle that whatever brings the regenerative capacity out of control is wrongdoing. In order to reach sustainability, every good citizen should have the mandatory responsibility to conserve the biosphere and pass it over to the next generations.

The critical mass needed for the transition to the regenerative model, in the medium term, requires disproportionate investments in relation to the cash flow generated. Aggressive fiscal and monetary policies should reduce the financial burden of the transition until, in the long term, learning curves will start generating increasing returns. As risking to be stuck in the middle is not an option, trade-offs between long and short term and/or between environmental and social goals should be addressed with robust industrial policies (Sabel and Victor 2022). On their side, business should be aware that, thanks to increasing returns, decreasing liabilities and lower cost of capital, the regenerative model is the most powerful value creator. New jobs created by the regenerative transition require massive educational programs to develop the necessary specific competences. Special attention should be dedicated to developing countries: both as large suppliers of regenerative resources and as early adopters (with few entry barriers) of regenerative technologies. The public sector is expected to incentivize extensive investments in R&D and in capacity building of regenerative technologies.

9.3 Circularity, Changes in Consumption

In developed countries, consumerism is responsible for much higher consumptions than ordinary needs, while in low-income countries underdevelopment is often a cause of environmental damage. Some anthropic activities are those that make us distinctly humans, creating social and economic value, while others are useless or negative for society because they deplete too many resources and distort the economy. Though some of the latter can be banned, such as violence and war, in a liberal society forbidding most of the useless or negative behaviors would be a limitation of individual freedom. Education, paternalism ("nudging"), and taxation are solutions that democratic countries have developed, but they have clear limitations. Ecological education should nevertheless become a central study subject from primary to high school, all over the world, with the aim of consuming less, more efficiently, and sustainably. Assessing the ecological footprint of technology should be made possible by measuring the regenerative capacity needed to restore the natural resources which have been depleted and remediate the damages of pollution.

As far as pollution is concerned, we need to improve the environmental tax frameworks—mostly limited to refunding damages caused by environmental liabilities like carbon emissions, pollution, and waste—and reinvest more resources for scaling up renewables, carbon sequestration, and the circular economy/industrial symbiosis. Increasing these taxes and lowering others (*green tax shift*) is a strategy that should be pursued, as it creates a virtuous circle combining higher fiscal revenues to be reinvested with strong incentives for taxpayers to invest in regenerative technologies. Circular economy needs strong public support, with better regulations and infrastructures for recycling and strong fiscal support to overcome the exit barriers from extractive technologies and the entry barriers to invest in clean-tech and regenerative technologies. Last but not least, the risk for climate change to become irreversible imposes to boost research in carbon sequestration technologies.

9.4 Biosphere (Biodiversity, Agriculture, Conservation, Restoration)

As seen, sustainability can be reached only by intensifying the regenerative capacity of all ecosystems, terrestrial and aquatic, natural and artificial, and this requires conserving as much as possible natural ecosystems and reducing the ecological footprint through circularity. To assess ecosystems' sustainability, we need to classify ecosystem services, quantify their minimum thresholds and protect biodiversity accordingly. The agro-ecological transition from conventional to regenerative agriculture reduces the overdependence on agrochemicals and should be promoted for its positive impact on the environment and health. For food security and good health, regenerative agriculture should be associated with a more diversified plant-based diet and lower animal-based food consumption. To make food systems more efficient, also artificial food production (e.g., laboratory-grown meat) should be considered. Spontaneous regeneration has the full capacity to clean and heal the biosphere; however, it will not boost until ecosystems will be polluted. Therefore, to complete the transition before it is too late, we must add massive ecosystem restoration programs to the mitigation and adaptation actions. Over 400 million ha of degraded and abandoned cropland can be recovered and reused for forestation or agriculture.

All initiatives contributing to increase regenerative capacity should be boosted with technology and business innovation. The incentives should come from *payment for ecosystem services* (PES), which so far is only supported with mandatory environmental taxes. To uplift incremental initiatives, like ecosystem conservation and restoration, voluntary frameworks for the valorization and fiscal incentivization of investment in environmental assets and activities should be jointly promoted by regulatory and financial institutions. Resilience in developing countries should also be better financed by public–private partnerships.

9.5 A Systemic Approach

Mitigation, preparedness, response, recovery are the four stages of crisis management. Robust public–private preparedness programs directed to citizens and business would increase the level of perception and anticipate response to crisis. The private sector is expected to pursue the transition to the regenerative model with a pragmatic "learn-by-doing" approach, while the public sector should develop the interdisciplinary scientific approach and tools to measure needs and solutions. Governments should also adopt a systemic approach in the regulatory framework and accelerate fundamental overarching decisions to prevent climate and environmental disasters. A systemic approach also implies making a *smart use of artificial intelligence*, developing new tools, and implementing new ways for the transfer of scientific knowledge into policy-making. In order to make the systemic approach the way of addressing problems, complexity theories should become part of most undergraduate studies curricula.

The principles of the Foundation are exemplified in Fig. 1, while Fig. 2 shows the application of a measurement framework to assess the regenerative nature of projects of the companies. The framework assesses the ability to achieve goals in each of the five axes indicated in the Figure, as exemplified by the colored areas (in the example, for two RSF founding companies, as explained in Fig. 2). A report describing the measurement framework is in preparation.

10 Conclusions: Regenerative Anthropization

The model of development and the technologies we have inherited are intrinsically unsustainable, since they deplete essential planetary resources, and accumulate hazardous waste. Regeneration of the natural capital is the only process that can allow a real sustainability of our life on the planet. Due to the environmental changes typical of the *Anthropocene*, the stock of natural capital is irreversibly reduced and therefore we need to find a new equilibrium, able to ensure the ecosystemic services and prevent further erosion of natural resources. The traditional approach to sustainability, that tries to address one problem at a time, is ineffective and leads to a dramatic delay in the search for solutions to the environmental and social crisis. The future model of development needs (1) to address the main causes of unsustainability, starting from the social and economic ones, with a system thinking approach, and (2) to acknowledge that irreversible or very long-term transformations of the planet and of human demography do not allow exclusively nature-based solutions, but require a blend of nature and culture, through the concurrent contributions from science, technologies, and humanities. We suggest to call this blend *regenerative anthropization*.

Appendix

The Regenerative Society Foundation has been founded to promote a new regenerative model by leading enterprises, in a constant dialogue with citizens, the youth, policy-makers and the financial community.

Founders of the RSF

illycaffè, Fondazione Ernesto Illy, Chiesi, Columbia University, Davines, Nativa, Fondazione per lo Sviluppo Sostenibile (Susdef), GARC, Sammontana, ABOCA, Irinox, Aworld, Lombardini22, Carbonsink, Nzatu, 3bee, Lombard Odier, Persea, Generali.

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Declarations

Conflict of interest Andrea Illy is Co-chair and Paolo Vineis is Scientific Director of the Regenerative Society Foundation, a non-profit organization.

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