Redefining sustainability in the Anthropocene
A complexity-based paradigm for responsible research and regenerative economics

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Can the concept and science of 'sustainability' offer timely answers to today's global crises? Our analysis starts from the case of medieval Viking and Inuit settlers in Greenland. In spite of their 'advanced' culture and technology the Viking collapsed, whereas the Inuit kept adapting and evolving. From this we learn that sustainability depends on a balance among 3 spheres: 1. (local) biophysical processes generating life; 2. narratives on what it means to be human and on how man relates to nature; 3; economic and technological processes ('justified' by these narratives) for accessing nature's offerings. Sustainability ultimately depends on a civilisation's capacity to adapt its narratives (and the corresponding techno-economic system) to biophysical realities supporting life. The current techno-economic regime (with its growth credo) translates human progress in 'exploiting nature' and so justifies the destruction of ecosystems. A growing number of emergent practices use narratives reconnecting man with nature, and pioneer in regenerative economic tools, yet regime institutions keep them from gaining societal tract. How can (sustainability) science help to mainstream these resilient innovations before the collapse of living ecosystems?

Keywords : sustainability science; paradigm; Anthropocene; complexity; narrative resilience

Introduction

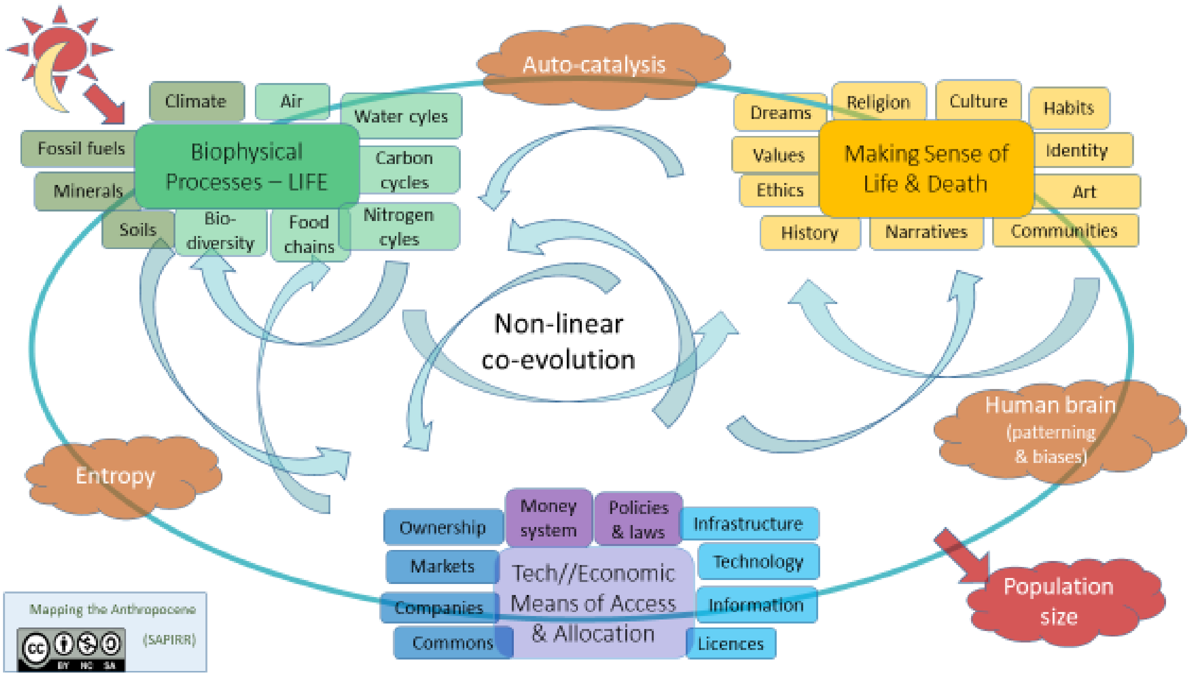
Scientists agree that today humans have an impact on planetary biophysical processes; they call our era the Anthropocene (anthropos is 'man' in Greek). There is some debate on the exact geological implications of the term and on the moral value of giving an anthropocentric name to a geological era (Crist 2019), but here we use it to highlight the *responsibility* of humans for the state of the global ecosystem life depends on. Human agency is taking us into a landscape unprecedented in human history: extreme levels of atmospheric CO_2, species loss at a much faster rate than the natural one, acidification and plastic pollution of oceans, etc. Sustainability science is meant as a response to those challenges. The question is under what conditions the concept and science of sustainability can bring about the necessary corrections in due time.

Mapping the determinants of sustainability in the Anthropocene

In his book 'Collapse' J. Diamond (2004) describes how some thousand years ago Vikings settled on Greenland. An Inuit group coming from (what we now call) the American mainland had also moved there. After 450 years the Viking community starved to death, whereas the Inuit stayed alive and well. The different fates of both groups can teach us crucial lessons about what makes a civilization (un)able to thrive sustainably. The Viking considered their European culture as more advanced than the Inuit hunter culture. With their ships they imported materials that were unavailable locally. They farmed, turned woods into grasslands for their livestock, logged trees to build houses, churches and even a magnificent cathedral. They ate meat from domestic animals, not seafood that had to be hunted at sea or traded with the Inuit. The archaeological evidence from the final phase of their existence on Greenland shows no traces of any fish consumption, but does reveal they ended up eating their calves and even their dogs.

There is some discussion about what explains the collapse of the Viking. Maybe it was caused by the fact that their economic and technological means (E.T.-means) extracted resources from the land faster than the local ecosystem could regenerate, or maybe by an external phenomenon such as a cooler climate. If the cause was external, why were only the Viking unable to adapt to the new context? And if their own cultural and economic practices caused their suffering, then why did they prefer to hold on to them and starve to death, rather than learn from the Inuit and survive? Why were they unable to adapt their more 'advanced' culture and technologies?

Figure 1. Mapping tool for the Anthropocene.

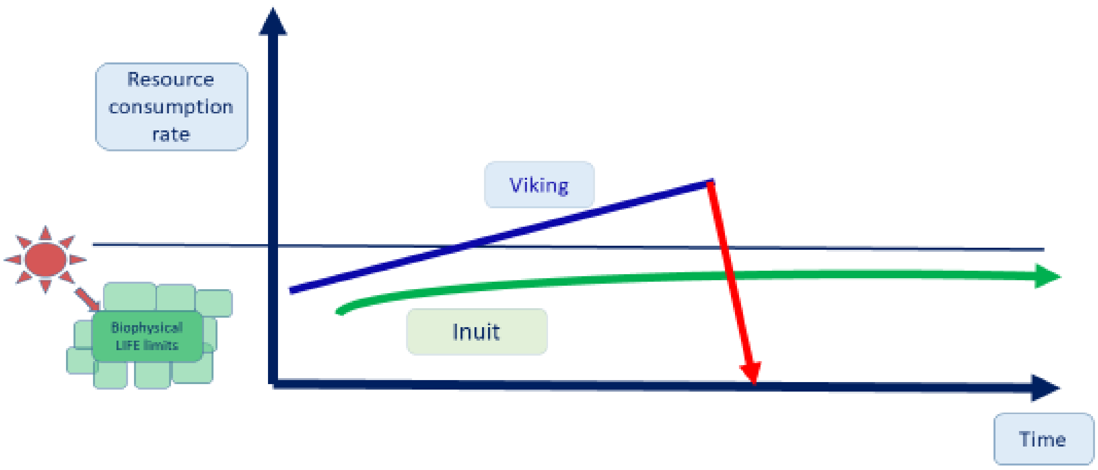


The story reveals the tremendous impact of the value narratives a civilisation tells itself. The way it defines its identity and its relationship to the ecosystem is at least as crucial (if not more) as the sophistication of its technological and economic tools. So if we map the elements helping us to understanding the contrasting fates of Viking and Inuit, three spheres are relevant (see Figure 1). The first one is the **biophysical, life supporting sphere.** The energy of the sun and the gravity of the moon set in motion hydrological and climatic cycles that create(d) the conditions for life to emerge and evolve. Over millions of years, the interplay between chemical elements and life forms turning solar energy in biomass (photosynthesis) led to the **autopoiesis** (or emergence) of soils, plants and animals organised as food chains, cycles of life and death, constantly adapting and evolving. The arrival of humanity in this web of life is a recent event. Man and other species together have shaped and cocreated a variety of bio-topographies (Crist 2019, Carroll 2016).

The second sphere is the way humans **make sense** of this complex web of life. Since our **brain** cannot process the constant stream of stimuli reaching us, cultures develop selective patterns to bring order and meaning in this chaos (Lent 2017). Civilisations descending from ancient Indo-European tribes build on the narrative that man is created in the image of God and that he is the culminating point of creation. They believe nature is a gift of God to humanity, a 'resource' for man to own and use as he wishes. Western culture today no longer refers to God to justify the objectification of life, but enacts the credo of human supremacy as if it is beyond any ethical questioning. Man feels justified in treating other life forms as mere matter rather than as beings worthy of respect. This narrative is so old it has embedded itself in language, in economic, political and cultural institutions and technologies. It is no longer recognised as a deeply political discourse for justifying the power man wields over nature, but is taken as a 'reality'. Indigenous peoples on the contrary have animist cosmologies emphasising respect for all beings and restraint in exploiting nature. Their literature on human-nonhuman relations emphasizes reciprocity, kinship and gratitude. The vision that human progress is proportional to the amount of exploitation, destruction and alteration of nature is alien to them (Crist 2019).

The third sphere concerns **economic and technological means** (E.T.-means) by which civilisations gain access to nature's offerings and distribute them among their members. Viking E.T.-systems were more complex and so dissipated available energy (in soils, plants…) faster than the Inuit ones, thus fuelling entropy at higher rates (Pogany 2015). Today's global E.T.-regime dissipates (mainly fossil) energy at rates never seen before in history. It is anchored to money systems, laws, infrastructure, rules of ownership, science, policies, etc. It reflects the belief that controlling nature is proof of our progress towards perfection, elevating us above the animals. In the guise of 'development cooperation' and 'multilateral' trade agreements, the West imposed its vision on nations worldwide, and justified this by calling indigenous people 'less developed' or 'poor'; early colonists even called them 'animals'. This Western vision drives the search for E.T.-systems that extract value from and pursue mastery of nature (Harari 2015). The narrative is so deeply embedded in E.T.-systems that regulate all aspects of our lives, that it is now very hard to change them; many political and business leaders even call it an 'unrealistic' idea (Latour 2017).

Figure 2. Non-linear development of civilisations

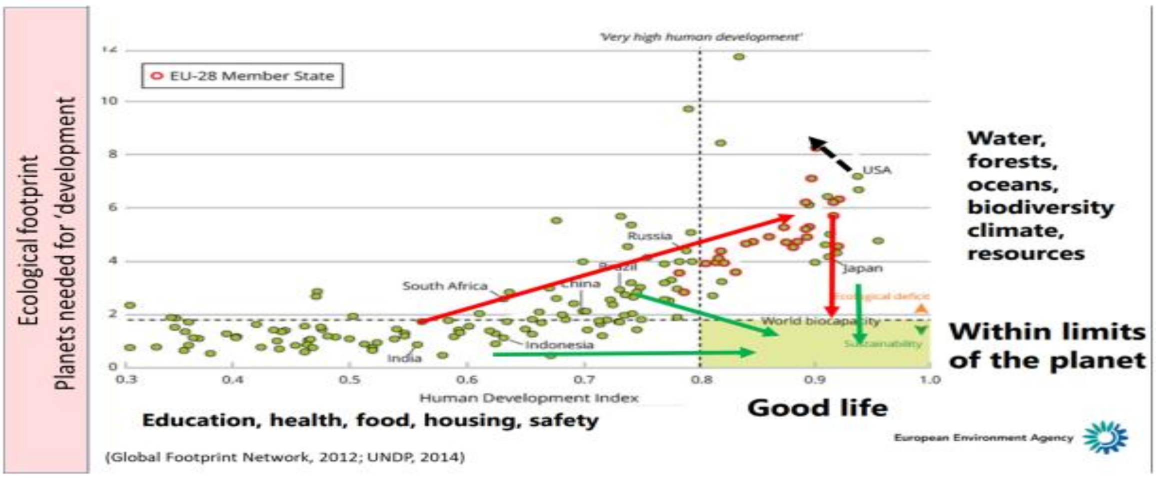


The story also reveals that human evolution is **not a linear progress** towards a brighter future (see Figure 2). For some time the Greenland Viking were successful as traders, builders and farmers. This may have reinforced their belief in their superiority (an escalating feedback loop). This success reached a tipping point when (due to changes in the landscape) doing 'more of the same' did not bring them more prosperity, while they seemed unable to do 'something else' (e.g. learning from or trading with the Inuit). If a civilisation can adapt in time to ecosystem changes (landscape pressures), it is sustainable. If however it moves away from of this balance and is unable to adapt its narrative and E.T.-means, collapse is a more likely scenario. The initial success of a culture is reflected in the growing size of its **population**. Yet the capacity of a local biosphere to regenerate (and increased available energy) does not grow, as it is determined by the scarcity of sunlight and of materials (e.g. soils and plants) that store solar energy for human use. Once there are more mouths to feed than the landscape can provide for, further growth becomes a risk. If a civilisation can keep its population in check, it is easier to be in balance with nature.

Diagnosis of our time: are we any wiser than the Vikings?

The European Environmental Bureau (EEB) published a graph showing the relation between the United Nations' (UN) Human Development Index (HDI) and the planetary footprint of nations (see Figure 3). The HDI combines metrics on education, life expectancy and income per capita; it shows ten degrees of development. The planetary footprint stands for how many times a country consumes what Earth can provide. Not a single country ranking high on 'development' remains within the limits of (one) planet Earth; most high HDI countries need more than four. To bring all nations to high levels of development as defined by the UN, we need at least four planets. This narrative clearly is out of touch with reality (Latour 2017), so 'Human Suicidal Index' may be a more appropriate term. The way development is defined does not take into account the real Earth ecosystem humans depend on for their (physical and mental) well-being, but reflects the vision of a godlike man who is disconnected from Earth. Planetary overshoot results from treating nature as a divine gift that endlessly provides us with our 'resources' and absorbs our waste, and flawlessly increases its regenerative capacities to keep up with our needs and desires.

Figure 3: EEB graph on Human Development Index and its planetary impact



Current E.T.-systems no longer function as means for human and planetary prosperity. Instead economic growth and technological progress are now its very *goals,* while people and planet are the resources it uses to achieve this. The question how this means-ends reversal came about is beyond the scope of this article, but one of the drivers is the money system. Money is created digitally by banks in the form of a debt which has to be paid back with an interest (fractional reserve banking with interest). As a consequence there is always less money around than we collectively owe the banks, and 'to make money' becomes the first aim of economic transactions (Pogany 2015; Lietaer 2011; Snick 2016b). Companies that make no profits go bankrupt. To keep up with an ever growing amount of debt-money, the economic system is forced to continuously increase its productivity. Since this inevitably involves (energy captured by) natural processes, planetary overshoot is inevitable: it is designed into the system (Chang 2011). Today social inequality between (owners of the) corporations that run the system and the great majority of mankind is enormous. Another factor that explains this sobering EEB-graph is that education, health care and income are organised by *redistributing* a percentage of (extractive) economic production (via taxes). In such a redistributive system, increasing levels of development requires steeper levels of extraction and exploitation, threatening human and planetary health. Western man has imposed on himself the Sisyphus task of rolling a self-made stone uphill (towards 'progress'), while this very stone pushes him out of (material and spiritual) balance with nature.

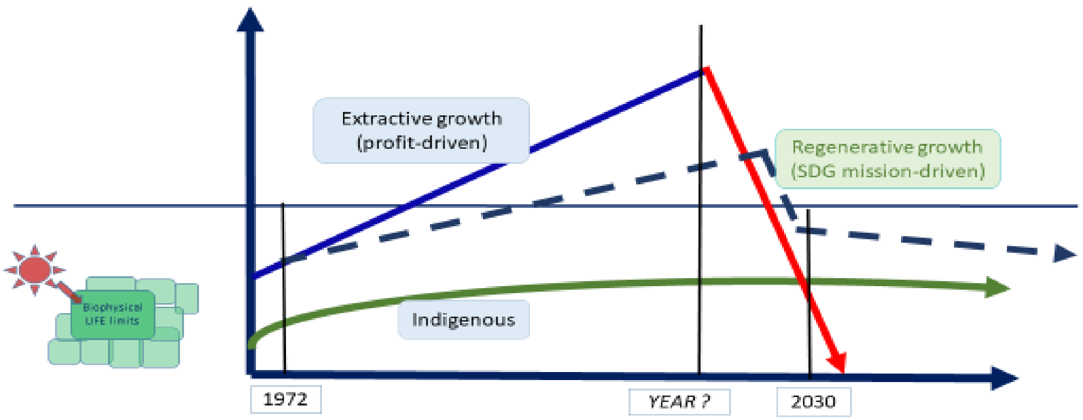
Economic growth and technological progress are intimately connected. As the growth imperative exceeds the capacity of the biophysical system and resources get scarce, research and innovation are needed to keep growth up, e.g. by inventing more aggressive technologies for extracting non-human life forms (fishing, logging…) or materials (fracking, mining…). Growth can also be pursued by reducing the cost of labour and making workers more productive; the science of human resource management serves that goal. Marketing uses insights in the (subconscious) working of the human brain to nudge people towards consumption. Planned obsolescence is a brilliant marketing strategy if you deny its impact on people and planet. As especially technological R&I requires huge investments, and money has to yield a financial return on investment, new technologies in turn fuel economic activity. This is an escalating loop, making it harder and harder for the E.T.-regime to change course and land Earth again (Latour 2017).

So are we wiser than the Vikings? Our society is based on the same Indo-European belief system framing man as a godlike creature, and nature as a resource to exploit. Science has freed itself from the censure of the Church, yet did not critically question the credo that man is above and apart from nature. Scientists are idealised as objective observers and smart managers of the Earth. Modern science does not question the claim that man has the right to destroy nature or engineer other life forms just to pursue his aspirations in academic freedom (Jasanoff 2018; Crist 2019). Our systems have done more damage to planetary ecosystems than the Viking ever did. So we can only claim to be wiser if we stop doing 'more of the same' in time (before critical thresholds of climate change, species loss and ecosystem collapse are reached), and learn from ecosystems and from indigenous people what a dignified human life on a thriving planet can look like.

Today there are many signs that this learning process is indeed taking place. Citizens and entrepreneurs no longer trust (unethical) banks or corporations to manage their affairs. New ownership models make the switch from extractive to cooperative (Kelly 2012). Biomimicry based inventions (mimicking the biosphere) are growing our natural intelligence and help us to understand that 'it is only an investment if it leaves the world better off' (Gorissen 2019: 2). Entrepreneurs and social innovators design companies that are regenerative and mission-driven instead of profit-driven, at the service of the common good (Wahl 2017). A growing group of researchers, political leaders, entrepreneurs and citizens go back to the commons as a sustainable system for governing (natural as well as cultural) shared resources (Bollier & Helfrich 2019, Ostrom 1990). Local monetary systems serving communities are growing in number (Lietaer 2011). Novel accounting systems no longer externalise the impact of economic transactions but reflect the real state of the ecosystem (Bauwens 2019). The soundness of using GDP growth as an economic measure is called into question (Raworth 2017). With (financial and other) support of local users, agro-ecological farmers learn to produce and distribute food sustainably. NGO's and companies learn from the wisdom of indigenous people in the global South, and focus on strengthening their local agro-ecological knowledge and practices (Azurduy 2019).

The list of initiatives that break away from the old story and explore new ones (learning from indigenous wisdom) is growing steadily. This shows our capacity to learn; we are adapting our vision of the good life, learn to find value in restriction and frugality, and diversify our pathways for achieving a quality life with healthy restraint. This desire to change course is expressed in the Global Agenda 2030, adopted by the UN in 2015. It lists 17 sustainable development goals (SDGs) that are not a choice menu of separate aims, but an interdependent agenda in which each goal must also contribute to (or not interfere with) the other goals. The agenda has been criticised because it includes economic growth (SDG8); this is seen as a sign that corporations sabotage the Agenda by having their private goal (financial growth) integrated in it. Yet, what makes the SDGs a strong leverage is that they are explicitly proposed as a *global* and *interconnected* agenda, not just for the global South but also for the North. This creates an built-in self-correcting mechanism: if growth is (still) defined in a way that threatens other goals (extracting profit at the detriment of justice and ecosystems), then it is not the kind of growth the UN agreed to. The Agenda could be a leverage for redefining the goal of economics; instead of growing its extractive capacity to make money, it can only mean pursuing a *growing* capacity to create well-being for all while restoring ecosystems and to redesign economic and technological tools accordingly (Snick 2017).

Figure 4. Diagnosis of our time



The diagnosis of our time gives a mixed picture (see Figure 4). No doubt the extractive scenario (top line) remains dominant and the regime moves towards tipping points (collapsing ecosystems, loss of soils, disturbed climate patterns, mass migration, etc.). On the other hand an abundant wellspring of niches (shown as the dotted line) are exploring and learning how we can 'land on Earth' again and live sustainably in an ethically and socially just way. The question now is whether the concept and science of sustainability can be helpful for our civilisation to leave the extractive model and shift to the regenerative pathway in time.

3. Does science make us wiser than the Vikings ?

Even a superficial look at the literature reveals that the sustainability concept is used in often contradictory ways. In broad lines, sustainable development can refer either to efforts to sustain the current view on development and growth (weak sustainability), or to efforts to adapt our vision on development and allow life on Earth to sustain itself (strong sustainability). The first approach leaves the basic narrative on human supremacy and entitlement to exploit nature unquestioned. It aims at incrementally improving the E.T.-system so as to guarantee 'sustained' extraction in a changing planetary and social context. Weak sustainability 'improves' the E.T.-system without looking at its deeper structural flaws, false assumptions or ethical weaknesses.

Strong sustainability is closer to 'learning from the Inuit', as it implies a deep questioning of the values inherent in the dominant system. It does not just treat the symptoms of current crises, but tackles its root causes. 'Root' in Latin is 'radix', so this is a more 'radical' approach. It pioneers with regenerative designs, community currencies, commons, and so on., E.T.-tools outside the dominant framework. This outlying position makes it hard for the regime to recognise or support them; they don't fit the normal narrative and may be perceived as untrustworthy or subversive. 'Radical' is often associated with aggressive or destructive, connotations overshadowing the ethical concerns and deep respect for life driving these pioneers. Within in this complex linguistic and institutional field sustainability science has to find its own position.

Before we look into the impact of sustainability in science, is useful to first describe the current R&I system in terms of the Anthropocene map (see Figure 1). Historically R&I is embedded in institutions that only look at (aspects of) one single sphere. Natural sciences study the elements and dynamics of the biophysical system. Narratives and values are the domain of social sciences and humanities. The E.T.-sphere is divided among various branches of applied sciences (such as economics), engineering sciences and disciplines studying specific institutions (politics, law, etc.). Ethics and epistemology e.g. are institutionalised as subfields of philosophy, not as the capacity and obligation of all scientists to reflect on their ontological and normative assumptions.

The current academic system was built (in the Middle Ages, i.e.) during the Holocene, and this has a profound impact on its underlying ontology and epistemology. A paradigm is a set of rules and conventions agreed upon by the scientific community; it defines valid ways to do research and sets the parameters for assessing scientific progress. In medieval times the paradigm was based upon the belief that – as stated in the Bible – God created all that exists, and that creation must reflect God's perfection. Planets were believed to move in circles since this is the most perfect form. This premise did not allow to predict planetary movement very accurately; such non-predicted phenomena are called anomalies, and they reveal the weakness of a paradigm (Kuhn 1962). Yet, for fear of being excluded from their community, medieval scientists did not reject the model but 'improved' it by adding more circles (epicycles), i.e. by doing 'more of the same'. Astrological maps became extremely complex compilations of epicycles upon epicycles, but science made progress and was able to predict planetary movements with increasing accuracy. When Galilei (who by then had a new lens: the telescope) did propose the ellipse as a more appropriate model (reducing anomalies), he did not *improve* the paradigm but *replaced* it. That is what distinguishes 'normal' scientific progress from a scientific revolution.

Universities were not built since the Anthropocene started, but have their roots in the previous era, the Holocene. This era started about 12.000 years ago when the climate on Earth stabilised; this meant humans were no longer forced to roam the continent to find food (as in the previous era when ice ages and interglacial periods radically altered ecosystems). It allowed them to develop agriculture, settlements and cities, writing and culture. Given this long stable context, medieval scientists assumed reality could be divided in separate parts without interconnection. When manipulating 'their' field of reality, all other fields were believed to remain unaffected ('ceteris paribus'). Scientific 'progress' meant that reality was split up in ever smaller domains (sub-specialisms). On this small scale – disregarding interactions of one part with other phenomena – it is of course possible to find regularities that can be expressed in mathematical equations. Given the 'eternal truth' of mathematics, this fed the belief that objective truths about reality (unchanging laws of nature) were discovered. Scientific progress was increasingly associated with quantifying reality, and dismissed qualitative aspects of life as 'subjective', belonging to the domains of arts and religion, not science.

The separation of reality into faculties and laboratories in 'ivory towers' remains the norm today, and the ceteris paribus assumption lives on. Most scientists and engineers claim that an innovation with a proven positive effect in the laboratory (where other parameters are kept stable), when rolled out at large scale (i.e. by 'bringing it to the market') will lead to a positive impact in society. Applied science and technology are deeply dependent on the separatist, specialist approach. In stable contexts causality appears to be linear (if A then B) which allows scientists to predict and control the outcomes of their experiments (if more A then more B). Since (only) at this small scale stable correlations can be found and outcomes predicted, the entire current system of technological innovation is in fact the brainchild of the Holocene. The financing of research and innovation is still mostly based on the division between 'pure' science (deemed to discover objective truths about reality) and 'applied' science (using those insights in the workings of nature and exploiting them for improving life via economic growth). The amazing inventions resulting from technological progress can be taken as proof of the (initial) success of this paradigm, yet current crises are increasingly putting it under pressure.

The Anthropocene (man-made) crises are in fact anomalies challenging the Holocene (specialist) paradigm. The debacle with antibiotics – once a great innovation in the laboratory, now one of the major health risks worldwide – was not predicted (and certainly not intended). In their laboratories researchers determined the effect and safety of this medication at the level of the individual patient, yet did not control the real impact of massive dissemination (fuelled by the profit urge of pharmaceutical companies and changing consumption and prescription patterns) in an interconnected world. It resulted in infiltration of antibiotics in ground water, undermining the immune system and creating the conditions for mutations that show up as superbugs. This is a wicked (non-linear) problem: yesterday's solution turns out to be today's problem. Our capacity to roll out 'more of the same' solutions is weakened (antibiotic resistance in bugs), yet it is hard to do 'something else' given the huge power of (academic, pharmaceutical, economic…) regimes.

Many technologies show the same flaws: they are tested in laboratory settings (with a narrow risk analysis) at a small scale (e.g. individual consumer). The effects of their large scale 'translation' on the co-evolution of life cannot be judged in a laboratory. Foreseeing societal impact and judging acceptable levels of (systemic, large scale) risk can only be done in transdisciplinary setting using a complexity lens, i.e. anticipating as much as possible interferences with and feedbacks from other spheres. These include not only the effects e.g. of medication on soils, water and evolution (even if mutations cannot be foreseen), but also on our growing expectations in terms of health and ageing, on our weakened capability to organise a type of care that strengthens the self-healing capacity of the body and the ecosystem, etc. Plastic, an 'initial success' in terms of consumer comfort, turns out to be deadly for the oceans (crucial sources of our food for many species and climate regulators). The same goes for electronic devices, fertilizers, nanotechnologies, pesticides, cars, etc. Wicked problems occurred not because the techno-scientific system planned them, but because it was (and still is) blind to the systemic interdependence and complex dynamics of life.

The second industrial revolution, enabled by technological innovation, allowed for increasing extraction of materials and for the mass production of consumer goods. Since the 1950's this model has been rolled out globally (for companies need 'growing markets'), leading to what is called 'the great acceleration' (McNeill & Engelke 2014). It enabled world population growth and comfortable lives for many people, but at the cost of massive ecosystem depletion. Competition for resources is getting increasingly fierce, fuelling geopolitical tensions (Krastev & Frank 2015). Instead of bringing its narrative back in harmony with Earth, our civilisation now defines human beings as competitors in pursuit of their self-interest. Education plays a key role in this, for the industry needs talents to win the competition. At an academic congress on 'rethinking global engagement', former EU president Van Rompuy said 'Europe's projected skills shortage risks being further exacerbated as the global geography of human capital shifts East, and competition to attract talent intensifies. We need popular support for accepting more skilled economic migrants' (Van Rompuy 2019). In other words, after the 'grab for Africa' we now proceed to the 'grab for Africa's and Asia's talented children' to be deployed as soldiers in the economic war Europe wages against their own countries. This is presented as an evidence, not as a construct that must be changed to achieve the SDGs. Even our leaders are no longer able to unmask this narrative as destructive of the values Europe loves to pride itself on (Crist 2019; Snick 2016a).

Many of the world's most outstanding academic institutions play a leading role in this race to the bottom. The intensive interaction between nature and E.T.-systems (rooted in human supremacy narratives) brought the emergence (autocatalysis) of a complex global system (Anthropocene), in which various parameters (climate, biodiversity, soils, etc.) are no longer stable, but interact in nonlinear and incontrollable ways (Chapman 2015). The loss of stable stocks of everything and of a stable climate is at the heart of current societal crises. These cannot be tackled by adding 'epicycles' to the same kind of thinking, but require a new (complexity based) paradigm. Does the concept and science of sustainability enable research and innovation to adopt this new paradigm?

4. Does sustainability science offer new perspectives ?

The crises have reached the front pages of newspapers only recently (as e.g. climate change brings *spectacular* hurricanes and *dramatic* school strikes), but the risks have been visible for almost half a century. As early as 1962 biologist Rachel Carson warned about ecological damage caused by the agro-industrial use of pesticides (Carson 1962). Since in 1972 the 'Limits to growth' report to the Club of Rome was published and sold in over ten million copies, academic, political and economic leaders were informed that the extractive scenario is unsustainable (Meadows et al.

1972). So not all current crises are unforeseen or unpredicted anomalies, yet the scientists who foresaw them, were often marginalised or not taken seriously.

Yet, in response to these early warnings, some pioneers started proposing more adapted scientific approaches. Systems thinking was developed in order to better understand the interdependency between human and natural systems, and to explore leverages for system change (Meadows 2008; Midgley 2000). Ecological economics study how an economic system can take entropy into account (Georgescu-Roegen 1971). Yet, as a whole the academic world has been very slow to accept this holistic paradigm, and it remains locked in to the specialist progress-discourse. Many researchers and research groups propose new (systemic, transdisciplinary) ways of bringing sustainability on the academic agenda, but these often remain isolated initiatives that do not inspire the whole university. In general the extractive economic model (and the technological regime that supports it) is still the dominant discourse, with 'radical' alternatives as side-branches.

The division of sciences into separate siloes and its institutionalisation in medieval structures (designed originally for the transmission of godly truths) in fact makes it very difficult for science to contribute to strong sustainability and to the co-creation of adaptive evolutionary pathways (Chapman 2015, Crist 2019). If sustainability is integrated in academic institutions, very often it is (just like ethics) 'neutralized' by treating it as a separate discipline or a new specialism (mostly part of the natural sciences). It is not embraced as a paradigm for all science in the Anthropocene, one that requires it to break out of siloes and to redefine its aim from 'increasing competitiveness' to 'reinforcing societal wisdom' . Most solutions to current challenges proposed by the R&I system therefore can only be qualified as weak sustainability. Some examples can illustrate this.

A lot of research in sustainability boils down to the search for 'green technologies'. Because of their enclosure in disciplines, using a lens focusing on one subsystem but blind for interactions with other subsystems, most solutions are mere improvements of the current paradigm, adding social and ecological corrections as epicycles but leaving the basic model unchallenged. This system-blindness feeds e.g. the belief that replacing fossil energy by renewable energy will allow for continued (or 'sustainable') economic growth. The reasoning is that solar energy is unlimited and imposes no limits to growth. What this overlooks or conceals, however, is that solar energy has to be captured and stored by material interfaces to be useful for humans. Solar panels, grids and batteries are needed to make solar (or any kind of renewable) energy run our machines. Most minerals allowing us to capture and store renewable energy are scarce and non-renewable; so for all practical purposes, solar energy is *not* abundant but just as scarce as those materials (Pogany 2015). Switching to green energy may at best solve one problem (CO2 emissions) at the cost of creating a range of others (mining, displacement of human and nonhuman populations, pollution, geopolitical conflicts over scarce resources, etc.). Moreover, by presenting any kind of renewable energy (including hydrogen) as clean and abundant, societal expectations and consumption patterns may well go up (a rebound effect), leading to an escalation of extraction, transport and pollution, and leading to the destruction of ecosystems.

Another solution that is often put forward to address resource depletion is to find new materials (possibly mining on other planets) to substitute scarce ones. Undoubtedly there is no economist who really believes that all resources (minerals, rare earths, metals, …) are renewable (on a human time scale). Many of these materials were deposited during the formation stages of our planet, and geochemists have a pretty accurate idea of how much of them (including soils) is available in locations where it is 'economically sound' to extract them (i.e. where extraction does not cost more than can be gained from it) (Sverdrup & Ragnarsdottir 2014). With the current rate of extraction the tipping point for (profitable) extraction of most materials is foreseen around 2030. Those scenarios are based on current extraction rates and do not take into account increases due to the fact that more countries aspire Western life styles. So substitution is not a solution of the problem, but an acceleration. It means we are building an infrastructure (electric cars, batteries…) on materials that will be unavailable in about ten years. And we are creating cultural addictions that increase the demand at a much faster rate than (exoplanet) mining will be able to fulfil.

Moreover, we are very busy creating a massive amount of electronic waste with chemicals leaking into the environment; processes like corrosion and osmosis cannot be controlled on beaches in the South where our old electronics are dumped and where our plastic washes up. Scientists and entrepreneurs now propose the circular economy as a way towards sustainable growth. This may be a good solution at the scale of a company or sector (extracting value from waste). But since it does not do away with the growth imperative, the result is only relative decoupling (using less resources per unit of growth), not a decrease the total use of resources (absolute decoupling). Given the laws of thermodynamics a perfectly circular economy (without waste and dissipation of energy) is impossible on this planet. Launching our machinery in orbits away from the planet is no solution either, as gravity makes old satellites and spent rocket stages collide and disintegrate, increasing the risk new space crafts are destroyed by a collision with man-made orbital debris. Given the laws of gravity, space debris can only disintegrate and spread further. When God gave us the planet, he forgot to provide us with the remote control for turning off gravity and entropy.

It is remarkable that most scientists use rigorous methodologies in the lab, but when it comes to judging the societal impacts of their innovation after being rolled out in the real world, they say they *believe* them to be beneficial. Rarely do they put this credo to the test with methodological rigour; it is pronounced as a truth claim, not as a hypothesis. This is complicated by the fact that complex systems may have different patterns at different scales. Climate change, for example, makes people suffer from heat waves, and a 'normal' solution is to produce air-conditioners to stabilise the climate in our houses. Yet, as these devices require energy – for mining materials and for producing, transporting, running the appliances and cleaning up the waste when discarded – they contribute to an increase of gashouse emissions and thus to even hotter summers: a vicious circle. A balanced system at small scale (house) leads to an escalating system at a larger scale (global climate). To find to a systemic solution that takes into account planetary dynamics and human responsibility in the Anthropocene, the first question to be asked is if it is better to produce more (maybe 'greener') air-conditioners, or on the contrary to *avoid* the production and sales of this kind of technologies, and instead focus on ecological ways to keep the climate stable (e.g. reforestation). Yet today no company (or for that matter research institute) can survive if its aim is to sell as little as possible; the current money system forces economic actors to not talk about systemic risks and ecological solutions, and to present growth (consumption) as 'evidently' good for society. So if science wants to contribute to strong sustainability, its primary focus should be on redefining its own paradigm; it should join forces with societal pioneers to cocreate regenerative cultural models and adapted economic, legal and financial tools.

Sustainability research hardly ever thematises the growth of the world population as a risk for our chances of survival. Population control cannot be achieved by imposing technical solutions, but that does not mean it should not be analysed as a driver of planetary depletion. The size of the world population determines how much pressure man puts on nature's bounty, and for mankind to live in harmony with species that depend on large wild landscapes, it should shrink to a more sustainable level. Evidently, until the population sets at this lower level, the demographic pyramid will be upside down, with few children and a large proportion of older people. This requires a thorough rethinking of aging policies and care systems, but when using a complexity lens more pathways for innovation become visible, enabling us to think outside the box and envision radically different care systems (Snick 2019). Sustainability scientists often treat population growth as an inevitable fact. Others see longevity it as a desirable goal, in line with man's dream of immortality, and do not mention how this impacts demographics (Harari 2015). Still others refer to it as a 'factual' justification for increasing E.T. extraction, e.g. via industrialised or bio-engineered food production systems that continue the exploitation and alteration of nature.

All these examples show that although sustainability is appearing on the research agenda (mainly in natural sciences and engineering), it is approached mainly from within the Holocene paradigm that caused the current societal crises in the first place (weak sustainability). Even if some universities start with more radical transdisciplinary, systemic approaches, these are not rolled out university-wide. In almost all universities the mainstream economic model is still taught as the 'normal' (or normative) one, while (strong) sustainability innovations are kept marginal.

Future-proof alternatives: a new paradigm for strong sustainability

Physicist Max Planck once said that science advances 'one funeral at a time', meaning that a new scientific truth does not triumph by convincing its opponents, but because these opponents eventually die, and a new generation grows up that is familiar with it. Climate change and species loss however do not wait for funerals and academia urgently has to step up its efforts. Radically alternative pathways for research and education – aiming at SDGs – are slowly emerging. A Belgian university college (Howest) has developed since 2016 an educational program for 'Network entrepreneurs', training their students to set up regenerative entrepreneurial initiatives (including the design of community currencies). An organisation like the Copernicus Alliance, a European network of universities and colleges committed to transformational learning and change for sustainable development, offers a platform of exchange and mutual learning. Some European research projects on 'Responsible R&I' (RRI) have explored ways to embed strong (i.e. complexity-based, common good-oriented and cocreative) sustainability research in the R&I system (Snick 2017). Can these initiatives have the necessary impact in time?

In the words of Planck, if a new generation grows up that is familiar with a new truth, that is the way for this truth to triumph. To let our civilisation shift to a sustainable path, a new education is key. Sustainability should no longer be enclosed in a specific field of study, offered to students as a mere option in addition to the 'standard' package. Every young person should understand why the current course of society is like walking in the footsteps of the Viking; they should also learn that today other trails are being explored, with a sustainable and peaceful world (SDGs) on the horizon. They have to be informed that other economic systems exist, even if they are still fragile and fragmented and struggle to be accepted by the (economic, legal, cultural) regime. To hide that information from them and to keep presenting the extractive model as the only 'realistic' one, is immoral, for it robs them of their freedom to imagine less destructive futures. Young people must be freed from the pressure of the extractive and competitive regime and be allowed to cocreate a future in peace and partnership (SDGs 16 and 17) with nature. They should be given the freedom to learn from indigenous wisdom and be stimulated to design regenerative pathways.

Typical university (college) classrooms are auditoria. Through their very architecture these spaces convey the message that the teacher/expert in front 'knows' while the student (passively, individually) 'learns'. Since we left the Holocene, this design is no longer adequate to prepare students for the reality of today. It is suitable for teaching them to master small (relatively stable) parts of reality (useful for developing new technologies). But in as far as education wants to bring about to a 'radically' better society (with or maybe without those technologies) the auditorium – like the specialist laboratory – is no longer the place to learn. We know for sure the future cannot be an (unchanged, stable) extrapolation from the past, as the tipping points our civilisation is headed for are approaching faster than scientists predicted. If we want young people to learn how to thrive within nature's boundaries, then the best teachers are nature and the indigenous people who for centuries (until Western economies started intruding in their world) lived in harmony with the natural world. The best laboratories where the future can be studied are the regenerative initiatives and new economic practices that prepare for a sustainable (SDG-conform) world. They can inspire students to think outside the academic box, to acquire holistic knowledge, to shape 'social' entrepreneurship in a healthy planet, supported by regenerative financial, technological and institutional tools. Many of those institutional leverages still have to be developed, so academia should have a lot to contribute. Higher education for a sustainable future has to be nourished by four 'placentas' – allowing new life to grow without controlling it:

1. HOPE. Young people today are overwhelmed with scary news about what's wrong with society and with nature; they hear that the lifestyle they cherish to may no longer be possible. These negative messages lead to reactions of fear and denial. In order for them to open up to alternative futures, an inviting and nourishing environment is needed (Lipton 2008). Field trips (to nature, to regenerative initiatives, to indigenous communities) or service learning therefore are powerful learning settings: they give students hope by showing in real life that the alternative is there and that it is beautiful (even if still fragile). Universities should stop immediately teaching the extractive economy as the only 'realistic' one, for (in more than one respect) this is a lie, fake news. Student initiatives like Rethinking Economics are important partners in this. Also, the perspective of reducing the human population to a level in balance with the ecosystem should be presented as a hopeful one, and not as undesirable (from the human superiority point of view) or unfeasible (as this restricts the freedom to imagine other futures and may thus become a self-fulfilling prophecy).
2. COMPLEXITY. Young people (and their teachers) should get familiar with systems thinking. This cannot be done by just reading theoretical books on complexity, but it also requires skills and daily practice, like learning to use a (new type of) compass. This should protect them from the fallacies of linear (Holocene) thinking and help them to be more prudent as future leaders, researchers, entrepreneurs or citizens. In the Anthropocene we have to learn to 'swing the system' (Meadows 2008) and see unpredictability as a chance to be creative.

Learning to 'embrace complexity' can be practiced in playful and fun ways (Booth-Sweeney & Meadows 2010) and by using mapping tools on a regular basis.

3. STORIES help young people to reflect on deep values and (blind) assumptions, and to discover other narratives. Stories do not just speak to the brain, but also to the emotions and the empathy of learners; that makes them powerful tools for envisoning other futures; they allow learners to feel what it could be like. Stories can be about how nature regenerates after the reintroduction of key species, or about how people learn valuable lessons on love and life, but also about the people and non-human beings whose history was silenced by supremacist culture (Kingsolver 2000 & 2012). It can help them to embrace a future where the human population is brought back to a sustainable scale and where people express their love for children in other ways than by putting their own offspring on an already exhausted planet.
4. COCREATION. The term 'Anthropocene' should keep us acutely aware that humans cocreate and are responsible for life on Earth. Cocreation has to be an ongoing, iterative dynamic process of self-reflection and adaptation, especially in an unstable, post-Holocene context (Chapman 2015). Preparing youngsters for the future requires active (not passive) and collaborative (not competitive) learning. Involving students as co-experts in transdisciplinary research projects can be a powerful way to achieve this (FoTRRIS 2018).

This last paragraph is merely a proposal and an invitation for further reflection and discussion, not a final conclusion. What higher education and research in the future should or could look like, is itself a matter of cocreation.

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