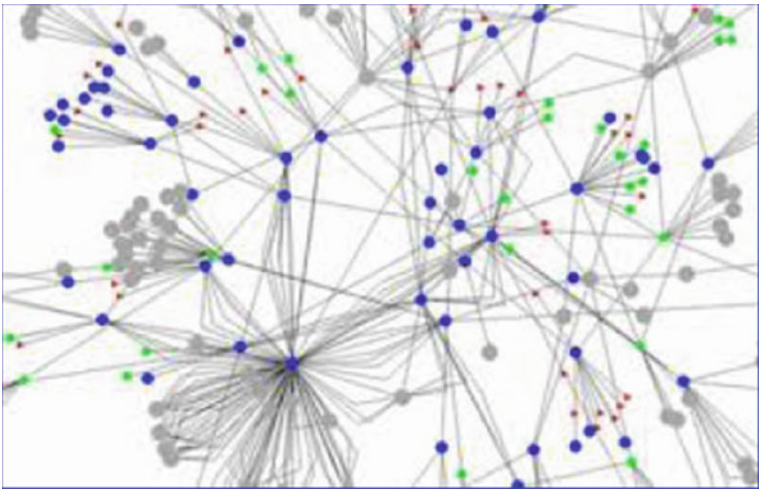
Quantitative Sustainability



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Quantitative Sustainability

Interdisciplinary Research for Sustainable Development Goals

Springer

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Foreword

Why Interdisciplinarity for Sustainability

Sustainability. The best definition of sustainable development is still the one proposed for the first time by the United Nations Brundtland Commission Report "Our Common Future": *meeting the needs of the present without compromising the ability of future generations to meet their own needs.* However, when you start digging, many questions arise: which needs? how far in the future? is there a science? is it possible?, etc. For example, one of the questions I ask myself as a chemist is whether Earth is a closed system relative to the Universe, if it reached thermal equilibrium, or if entropy continues to increase. Apparently, there is quite a bit of entropy around, most of which is created by us, but is there a relation between entropy and sustainability?

Several of these questions are first of all philosophical, but most of them are scientific. Until now, we don't seem to have definitive answers, so the only possible sustainable strategy is to minimize the production of entropy by making processes more efficient. It is not clear whether we have already passed the point where the future can no longer support the flourishing of humans and other forms of life, but we must consider the possibility of abrupt, non-linear changes in the near future.

Complexity. One of the reasons we still know so little is that the subject is enormously complex, due to the interdependence of hyper-complex and intertwined systems like the society, the economy, and the environment. Complex systems are not linear and behave in a non-predictable way. Hence, any attempt to manage sustainability with a reductionist approach is doomed to fail. Only a systemic and, consequently, interdisciplinary approach can prevent failures. Social and natural sciences must go hand in hand, and this makes the problem of interdisciplinarity even more difficult.

Because of complexity, knowledge is not expected to be produced in a linear and cumulative way; only empirical and observational relationships can be detected with powerful tools, such as those provided by artificial intelligence (machine learning, digital twins, etc.). This approach creates the problem of access to big data sets

containing all relevant measurables and with good quality information. Most of these measurables have not been identified yet or are not available, and this determines a catch-22 situation.

Cognitive Gap. Extreme complexity makes it difficult for people to understand the challenges ahead and their solutions. Pre-crisis symptoms were very clear half a century ago, but the slow pace of changes made society live within a "boiled frog syndrome" situation. Now that the climate crisis reached emergency levels, we are experiencing stages of the grief cycle, from denial to anger, bargaining, and depression, which are not constructive because they trigger resistance to change as well as irrational and selfish behaviors.

Externalities like pandemics, wars, inflation, and social unrest, are on one side natural consequences of the chaos induced by the unsustainable world we have created, but, on another side, also big distractions from the urgency to solve the problem. As a matter of fact, planetary sustainability can be hardly pursued with conventional governance models, because the necessary conditions for consistent and right decisions, along with good execution-which include highly ethical and competent leadership, long-term mandates, and global scope-in practice do not exist in our world. Countries are not ready to limit their sovereignty for a global cause. The resulting short-termism, opportunism, cynicism, misinformation, instability, and inconsistency driven by gigantic financial speculation are not the right conditions to pull people and businesses out of their comfort zones to reduce their ecological footprint. Under such governance conditions, the tragedy of the commons is still the most likely scenario.

Understanding Our World. Studying sustainability starts with understanding our world, i.e., the birth of the planet, the origin and evolution of life, the mechanisms regulating the biosphere, the human impact, and many others. We shall start from the universal picture: if it is true that all the energy originates directly or indirectly from the sun and that life originated from chaos, that heterotrophic organisms appeared to clean the excess of oxygen that was intoxicating the primordial anaerobic biosphere, that the course of climate change can be abruptly changed by many possible co-factors, then interesting new surprises could change the situation.

As omnivores capable of moving resources around and exploiting them, rather than moving themselves towards resources, humans completely disrupted the natural equilibrium and exploited every ecosystem on Earth. Technological development, coupled with unimaginable solutions to protect human health and safety, has made the human civilization outnumber every species with a comparable body mass by a factor that can be estimated in more than 10,000. Moreover, contrary to any other species that ever existed, humans do not limit their activities to basic biological needs, but have developed all kinds of anthropic (i.e., beyond physiological) activities, which are responsible for a per capita energy consumption 18x higher than that corresponding to sheer food calories. The combined effect is that human ecological footprint can be estimated to be tens of thousands of times higher than any species, and the resulting planetary transformation has been so disruptive to be associated with an ecological era, *Anthropocene*.

For sure, it is not the biosphere to be endangered by humans, but the opposite. Natural systems adapt and evolve quickly, driven by the exponential growth of cellular replication, until conditions are favorable. Resource scarcity, diseases, competition, difficult environment, etc., are limits to growth, which cause populations to level off or to decline, paving the road to new species, and thriving on the new situation. *Homo sapiens* is still in the exponential growth phase, so we still have time to figure out whether we will be capable to adapt to the new biosphere inadvertently created by us, or if some catastrophic event will wipe us off the planet. Interestingly enough, removing the above-mentioned limitations would immediately reboot population growth. Because sustainable development depends on the same factors, sustainability paradoxically drives demographic increase, which has been the trigger of the climate crisis. Is there a vicious circle or even a paradox?

Assessing Our Development Model. The problem with sustainability started with the industrial revolution and its extractive and linear model. Since then, over a century and a half ago, our economy has kept depleting natural resources like they were infinite and producing an unlimited amount of pollution and littering at the end of the product lifecycle. Progress triggered super-exponential growth: to cope with the demographic explosion, energy consumption rose from ca. 12,000 TW in 1900 to 28,000 TW in 1950 (cagr 1.7%), ca. 120,000 TW in 2000 (cagr 3%), with nearly 80% of energy still coming from fossil sources. Total food consumption went from ca. 3.15 trillion kilocalories in 1969 to ca. 8.5 trillion kilocalories in 2019 (cagr 2%). The soil used for agriculture reached 50% of habitable land (twice as much as one century ago), at the detriment of forests, which now represent only 37% of the terrestrial surface. Arable land per person halved in the last 60 years from 0.36 ha/pp to 0.18 and cannot be increased due to saturation of suitable land.

So, are we running out of resources? There are probably still more detractors than supporters of the limits to growth theory presented by the Club of Rome 50 years ago. It is true that, since then, many production limits have been crossed thanks to productivity increases, but the impact is under our eyes.

Burning mineral carbon, sequestered and stored millions of years ago under the terrestrial crust, caused greenhouse gas emissions to exceed Nature's capacity to re-absorb carbon, resulting in an increased concentration in the atmosphere and climate change. Global warming might become irreversible and self-feeding once a redline of carbon dioxide in the atmosphere is reached. Agricultural production increased, thanks to improved agronomical practices, but at the detriment of other ecosystem services. Currently, agriculture is the second source of greenhouse gas emissions and the first cause of biodiversity loss, with a severe impact on the biogeochemical cycles. Finally, pollution caused by most economic activities accumulates in waters and soils, intoxicating the biosphere and hindering its spontaneous regeneration.

At present, we consume 1.7 times Earth's equivalent resources per year, depleting natural capital while endangering medium/long term food security and necessary ecosystem services continuity.

Developing a New Regenerative Model. Economic, Environmental, and Social sustainability are all reciprocally interdependent and equally indispensable. Environmental sustainability requires a new development model, which must correct the secular mistake that made the extractive model systemically unsustainable. In the combination 'Nature/Culture', the conjunction in the extractive model is 'or', assuming that science and technology could eventually free us from our dependence on Nature. Since, in reality, whatever we need for living—air, water, food, health— is 'Made in Nature', we must change the conjunction into 'and'. 'Nature & Culture' doesn't only mean a codevelopment of people and planet, but also using social and natural sciences to restore and heal the biosphere from the damages of the past. Social sustainability must take into account the projected population in the decades ahead and pursue poverty eradication through education. Economic sustainability needs growth as a prerequisite to payback investments. However, in this new model growth, which is a quantitative metric, must go along with development, which is a qualitative criterion.

The Regenerative Society Foundation, which I have the privilege to co-chair with Professor Jeffrey Sachs, adopted a framework made of three macro factors—Well-being, Circularity, Biosphere—and their mutual interactions. The goal is to rebuild the carbon stock, which until now is the only way to decarbonize the atmosphere, as well as to restore biodiversity, which is responsible for ecosystem's resilience and health. Consistently with the one health approach, which makes it clear that our health depends upon biodiversity, human health is the co-benefit pursued by this framework.

The foreseen dynamic is that healthy and happy people, conscious that their well-being depends primarily on the ecosystems where they live, reduce their ecological footprint through circularity; circularity minimizes resource depletion and avoids pollution, detoxifying the biosphere; spontaneous regeneration heals the biosphere, paying the dividend with better ecosystems.

The ecological transition from extractive to regenerative is a titanic endeavor, which will result from thousands of learning curves contributing to the energy transition (from fossil to renewable sources), the agro-ecological one (from conventional to regenerative agriculture), and the industrial one (from linear to circular economy). It must be approached in a systemic way, in order to understand, for instance, the completely different planet setting of our times compared to *Holocene*, the complexity and path dependency of the transition, and the balance between the given biocapacity, the human appropriation of the net primary production and the need to restore ecosystems. The waterfall impact of the transition will change our lifestyle. For instance, livestock consumes 70% of agricultural resources, and a diet too rich in animal-derived food also represents a risk to health. We will, therefore, need to change our diet to a more vegetable-based and a much more varied one. This is a challenge in the challenge because, although there are thousands of edible plants, nearly half of the world calories intake derives from only three crops (which is also one of the main causes of biodiversity loss).

An educated guess is that less than 50% of the necessary technologies for the transition to the regenerative model are already available and most of them are not mature yet. So, at present, we cannot even calculate their regenerative capacity. Exit barriers from the inherited extractive infrastructures, as well as the entry barriers to develop new regenerative ones, will make the phase in/phase out quite difficult and hopefully not too slow. To mention just a few of them: the new supply chains for solar energy need conversion and stocking technologies with capacity and energy density at least comparable to fossil fuels; most technologies underlying the production of goods and services must be redesigned to be powered with renewable energy; to ensure food security, in addition to reducing waste and making food systems more efficient, artificial food production should also be considered; waste becoming critical resources, they require reinventing reverse supply chains and infrastructures, as it happened for example with the development of sewage systems; reaching carbon neutrality requires developing carbon capture and storage as a brand new industry.

What the Trieste Laboratory in Quantitative Sustainability Can Do. The road towards the ecological transition is bumpy and we are still lagging. The impact of the climate crisis on environment, society, and economy is devastating and exponentially increasing. Mitigation, preparedness, response, and recovery are the four stages needed to manage the crisis. Robust public–private preparedness programs directed to citizens and businesses would increase the level of perception and anticipate response. Every organization and individual, with no exception, must mobilize. Businesses, in particular, are the most important stakeholders because everything in society is made by a company and because the private sector represents on average half of the GDP. Therefore, collectively they have an enormous power and economic advantage in embracing the cause.

After more than fifty years, notwithstanding the enormous work made by a plethora of governmental, intergovernmental, non-governmental, and private institutions, we still don't seem to agree on the definitive framework, methodology, and measures for sustainability. We desperately need to quantify the fundamental dimensions of sustainability and embed them into the economic value of goods and services.

Considering the interdisciplinarity of this process and the scientific humus existing in Trieste, with the relevant institutions dedicated to theoretical physics, advanced mathematical studies, biotechnology, oceanography, astrophysics, medical sciences, a Science park, a synchrotron, data science and artificial intelligence institute, and the coordination of all of them by the Trieste International Foundation, the TLQS can give a significant contribution in driving and accelerating the transition.

As far as more specific research is concerned, besides the terrestrial ecosystems to be regenerated (natural, rural, industrial, and urban), the aquatic ones are the most important and still neglected. With 70% of the oxygen produced and about 35% of the carbon sequestered, oceans are among the largest contributors to ecosystem services but, due to increased acidity and lower dissolved oxygen, are endangered by both the causes and effects of climate change. If we exclude marine protected areas and fishing regulations, there seem to be very few effective sustainable strategies for ocean conservation. OGS, as the main promoter of the TLQS, could strive to lead

international research supporting the future blue economy for sustainability, in areas such as carbon capture and storage, renewable energy production, innovative raw materials, ecosystems conservation and restoration, marine biodiversity, and others.

June 2023

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Preface

Let us begin with a citation taken from the prologue of the book "*The lunar men*" [1] by Jenny Uglow which tells about the stories of a group of friends belonging to *the Lunar Society of Birmingham* in the eighteen century. In a way, our laboratory is inspired by the innovation spirit of these men.

> The earth turns and the curving shadow sweeps round the globe. The sun sets, the moon rises, and all that is familiar feel suddenly strange. In an age before street lights, link-boys carry torches to see city-dwellers home, while in the countryside starlight and moonlight are the only guides… And in the eighteen century clubs are everywhere: clubs for singing, clubs for drinking, clubs for farting; clubs of poets and padding-makers and politician. One such gathering of like-minded men is the Lunar Society of Birmingham. They are a small, informal bunch who simply try to meet each other's house on the Monday nearest the full moon to have light to ride home (hence the name) and like other clubs they drink and laugh and argue into the night. But the Lunar men are different-together they nudge their whole society and culture over the threshold of the modern, tilting it irrevocably away from the old patterns of life towards the world we know today.

We still do not know towards which patterns of life we are going to *nudge our whole society*, but certainly we are aiming at a quantitative understanding of the modern sustainable development. Like the lunar men, we need to escape from the disciplinary barriers of sciences inside which we operate today, towards new and largely unknown borders based on an interdisciplinary approach.

Our interdisciplinary laboratory on Quantitative Sustainability is growing in the right place and at the right time. Friuli Venezia Giulia is a small region, but very rich in *Science and Technology*, located at the centre of the North-Adriatic area, a lively land of culture and innovation.

Trieste is the flagship of this innovation harbour, with a density of people doing research which is the highest in Italy and among the highest in Europe. The high standard of the research produced is the fruit of the settlement of three major national Universities and of most of the existing national Research centres, like for instance the National Institute of Oceanography and Applied Geophysics (OGS), together with the presence of prestigious international research Institutes: the International School for Advanced Studies (SISSA), one of the six Italian Advanced Schools,

two international institutes for the promotion of science in developing countries, the *Abdus Salam* International Centre for Theoretical physics (ICTP) and the International Centre for Genetic Engineering and Bio-technologies (ICGEB), with one of the highest percentages in Italy of foreign students. There is the largest national scientific district for innovation, the Area Science Park, which hosts a large European synchrotron radiation facility, ELETTRA, and one of the most powerful free electron lasers in the world, the FERMI.

All this, generated already in the fifties by the strategic view of a man, Paolo Budinich, a champion not only in Theoretical Physics, but also in Science Diplomacy, has become a splendid network of science and technology, well known worldwide, which has recently been awarded with the nomination by Euro-Science of Trieste as *European city of Science* for the years 2018–2020. A strong message given by the participants at the *Euro-Science Open Forum (ESOF2020)*, the final international event, organized by the Trieste International Foundation (FIT) in September 2020, has been the development of a North-Adriatic Summer Institute on Sustainability, of which our laboratory is the premise.

The fallout effects of the rapid growth of the research activity, together with the presence of important industrial settlements, like Fincantieri and IllyCaffè as well as important Insurance companies, like Generali and Allianz, have generated a rate of qualified employment growth in Trieste, particularly in the innovation sector which in 2017 reached the highest provincial percentage at a national level of innovation start-ups.

Not to forget the high level of science journalism, initiated by SISSA, with its Master in science communication and the organization of several science festivals.

This creative environment, most favourable to the birth of moving ideas, takes also the advantage of the social atmosphere, that pervades the city. The writer Jan Morris [2] described Trieste as *the Nowhere city …. not just as a city but an idea of city*, *and it appears to have a particular influence upon those of us with a weakness for allegory—that is to say*, *as the Austrian Robert Musil once put it*, *those of us who suppose everything to mean more than it has any honest claim to mean.* The people in Trieste never look surprised by anything, and at the same time is curious to know the new, the paradox, the unimaginable.

The figure in the back cover shows a long and beautiful pier in Trieste, just in front of Piazza dell'Unità, which points in a sort of nowhere, towards a *Leopardian infinity*, the unknown that we wish to reach.

The right place for Lunar Men, like us, looking at the science of sustainability.

Trieste, Italy — Nicola Casagli
Udine, Italy — Marina Cobal
Trieste, Italy — Stefano Fantoni
Trieste, Italy — Cosimo Solidoro

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1. Jenny Uglow, *The Lunar men*, Faber & Faber Limited, 2002.
2. Jan Morris, Trieste *and the meaning of nowhere*, Simon and Schuster, New York, 2001.

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