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The technique is never neutral. How methodological choices condition the generation of narratives for sustainability.

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"It is not uncommon for political programs to be decided in advance simply by the choice of what expert representatives are included in the circle of advisers."
(U. Beck [1])

Abstract

How to tackle uncertainties and ensure quality in integrated assessment for sustainability? To what extent does the choice of the methodology condition the narrative produced by the analysis? The present work argues that the two questions are tightly coupled. The technique is never neutral. If we are the tools of our tools, as suggested by Thoreau, then it can also be said that language is not only a vehicle for communication, it is the driver as well. For this reason, in sustainability assessment it is not unusual to discern a close relationship between arguments made and methods adopted. In the present work a set of six reflexive analytical tools – we call them lenses – is suggested which could be pooled to the effect to appraise and improve the quality of integrated assessment and the resulting sustainability narratives, and to alleviate the constraints of the method-argument dependency. None of the lenses is new and each has been used before. Never have they been used together. The lenses are (i) Post-normal science (PNS), (ii) Controversy studies, (iii) Sensitivity auditing, (iv) Bioeconomics, (v) Ethics of science for governance, and (vi) Non-Ricardian economics. The six lenses are illustrated together with a set of case/narratives/arguments. The lenses allow some narratives – or methodologies – to be shown as either implausible or inadequate, and new narratives to be developed to tackle pressing sustainability issues, which expand the horizon of possible strategies for a solution.

Introduction

Narratives are a key element of sustainability assessments, even while they are not always explicitly articulated. In turn, worldviews, values and imaginaries shape both individual and societal sustainability narratives, deliberately or unconsciously, particularly when solutions to complex challenges are sought and option spaces scrutinised. For example, the integrated assessments developed by the Intergovernmental Panel on Climate Change (IPCC) offer no scenario exploring the effects of discontinuing economic growth, globally or in the affluent countries, as policy options around sufficiency or degrowth were considered implausible, making continued economic growth for the next 80 years the default choice [2]. Whether one agrees or not on the choice, the example points to the fact that integrated assessments are unlikely to result in '*critical objective evaluations*' contrary to what was suggested by UNEP [3]. In reality, global environmental assessments *face a broad range of divergent political stakes, interests and ethical values, as well as different forms of disputed knowledge claims* [4] which must be somehow responded to in order to ensure the essential qualities of integrated assessments: saliency, legitimacy and credibility [5]. In global environmental assessments, the resolution of 'scientific' divergent viewpoints and uncertainties cannot be disentangled from political or ethical considerations, given the entanglement between facts and values, therefore integrated approaches are required [4]. The present work combines six different analytical lenses to critically appraise narratives for sustainability. The six lenses are complementary and are pooled to appraise and improve the quality of integrated assessments and the resulting environmental narratives. None of the lenses is new and each has been used before. Never have they been used together. This selection of lenses and proponents may result from a "contingent gathering of personalities dissatisfied with the dominant paradigms of integrated assessment", as noted by a perceptive reviewer. They can also be thought of as an advocacy coalition, if not yet a school, although the Centre for the Study for Science and the Humanities at the University of Bergen has become a common home where these ideas have currency and are disseminated in books[6][7], projects, articles, symposia and courses[1]. Undeniably, because of their history of cooperation, these authors and their closest collaborators can be thought of as an epistemic community. The vision of five of the seven authors of the present work is used in the context of a large EC funded research on the nexus between water, energy and food resources [8] (https://magic-nexus.eu/). In the MAGIC

[1] https://bit.ly/2WLbz0W, https://bit.ly/2NJKAyP, https://bit.ly/34BNGf7.

project a combination of these lenses is used to check the plausibility of: (i) justification narratives (the *why* of the proposed policy); (ii) normative narrative (the *what* of the proposed policy); and (iii) explanation narratives (the *how* of the proposed policy), where the three categories are taken from [9]. The results of the project show that there is a lot of "uncomfortable knowledge"[10] (unknown knowns) that is ignored in current sustainability discussions. So far, the collaboration across this contingent gathering of personalities has proven fruitful and enlightening for all of those involved. Our hope is that it will function likewise for the reader. Given the geographical collocation of the authors, and their engagement in EU policy-related research, e.g. in MAGIC [8], in the cooperation with the European Environment Agency, and in European science advice fora [11], the text reads as Europe-centred, but the implications for policy are general.

The lenses are (i) Post-normal science (PNS), (ii) Controversy studies, (iii) Sensitivity auditing, (iv) Bioeconomics, (v) Ethics of science for governance, and (vi) Non-Ricardian economics. The six lenses are presented using illustrative cases while focusing on the quality of narratives and arguments in integrated assessments for sustainability. The present work addresses two main questions:

- Is it possible to better tackle uncertainties and ensure quality in integrated assessment for sustainability?
- Is it possible to better deal with the fact that the choice of the methodology conditions the narratives produced by the analysis?

The present work argues that the two questions are coupled, because the technique is never neutral. If we have become the tools of our tools, as suggested by Thoreau, then it can also be said that language is not only a vehicle for communication, it is the driver as well.

For this reason, in integrated sustainability assessment a close relationship exists between arguments made and methods adopted. This relationship did not go unnoticed to the fathers of the ecological movement, with their early critique of risk and cost benefit analyses [12].

We show how the adoption of the selected lenses can provide an alternative or a critique to existing mainstream visions and imaginaries. It can be argued, for example, that

- while the EC 'Circular economy package [13]' contains valuable elements, a truly circular economy is not around the corner;

- decarbonizing European and global economies will not be achieved in a couple of decades;
- evidence-based policy suffers from serious pathologies of power asymmetry which would demand our urgent attention;
- trade may not be beneficial for those who trade diminishing return goods (e.g. raw materials) as compared to those who trade increasing return goods (e.g. high-end manufacture);
- pollinators decline - the closest likely ecological catastrophe - is the result of systemic institutional and regulatory failure.

These are just examples, and the positions taken in this work are not meant to represent a corpus, containing a unique revealed truth, which is offered as a substitute for existing narratives. Nor are they presented at the exclusion of other valid approaches which might be used to revisit common wisdoms. It will be argued instead that these lenses taken together already allow a considerable and useful broadening of the spectrum of existing discourses on sustainability. This entails, as it should, a critical analysis of some of the existing stories told about development, sustainability, and transitions, with their unspoken assumptions [14], and ethical implications [15]. Confronted with the present debate between techno-pessimists and techno-optimists [16][17], we propose an avenue to tackle transitions endowed with a pragmatic outlook and fungible instruments, while supporting the concept that original imaginaries need to be developed for a democratic and sustainable future of our relation with technology [18]. As discussed below, each lens provides a different check of the quality of narratives.

In the following sections we briefly illustrate the six lenses with a test case each. We than discuss what is achieved when these lenses are taken in combination.

First lens, post normal science

The lens

Post-normal science (PNS) [19] is foremost a set of practical insights in science for policy. PNS assists scientists and stakeholders to work together when facts are uncertain, values are in dispute, stakes high, and decisions urgent. PNS embraces complexity, and addresses the dangers of reductionism - the idea that every practical problem can be decomposed into a

sum of simple technical problems, or against the arbitrary distinction between facts and values, especially at the science-policy interface.

PNS also shows the ineffectiveness of a problem-solving strategy that reduces policy questions to technical problems, for example when implausible cost-benefit analyses are employed to monetize the value of environmental goods [20] or when the problem of food scarcity is presented as a technical problem of agricultural management and production volume rather than an issue of unequal distribution of power and resources [21]. PNS can be deployed in a whole range of issues, such as "eradication of exogenous pests […], offshore oil prospecting, legalization of recreational psychotropic drugs, water quality, family violence, obesity, teenage morbidity and suicide, the ageing population, the prioritization of early childhood education, reduction of agricultural greenhouse gases, and balancing economic growth and environmental sustainability" [22]. A historic theme for PNS is science's quality control and governance system [23][24][25][26].

PNS is suited for a broad set of "wicked" [27] policy issues, drawing credibility and legitimacy from its focus in the quality of the problem-solving process and products. Quality in policy-related research must encompass a plurality of perspectives and the recognition of different sorts of uncertainty. In this way, quality replaces truth as the focus of science deployed for the resolution of complex socio-environmental policy decision-making. Quality in PNS is assessed by an extended peer community, constituted by all those with a stake or interest in the relevant issue – such as accredited experts, affected or interested citizens, investigative journalists, or whistle blowers. The extended peer community has an important role in framing the relevant practical issue, and proposing the techno-scientific problems to solve, thus ensuring that a diverse and broad set of perspectives are included, and that no single interest dominates and constraints the problem-solving process.

In the context of the present proposal for an integrated set of lenses, PNS provides a commitment to openness, plurality and prudence in meeting the challenges of progress. Foremost, PNS' standpoint is to encourage multiple perspectives and ideational concepts, while at the same time promoting an active appreciation of the corresponding regimes of governance, of the involved actors, and of their interests, capabilities and stakes [28].

The lens in action: Post-normal concerns in a boundary organization - towards reflexive practices in knowledge production and appraisal at the EEA

The very concept of evidence, its operational definition and production, use and legitimacy are nowadays more challenged than ever. Trust in public institutions and their narratives is eroding, and the role of experts and expertise in governance is contested [6]. Under these new circumstances, known problems concerning uncertainty, ambiguity and scientific controversies are acquiring a renewed meaning, and relevance in the public debate. There is increased recognition of the emergence of 'socially contested facts' in opposition to a regime of 'socially accepted facts'. Such changes are likely to influence current and future environment within which the European institutions operate.

The European Environment Agency (EEA) is a recognized authoritative source of information on environmental matters, which publishes relevant assessments: EEA's State and Outlook of the European environment (SOER) 2015 had a potential audience of 55 million people in Europe. According to its mission,[2] "*The EEA aims to support sustainable development and to help achieve significant and measurable improvement in Europe's environment through the provision of timely, targeted, relevant and reliable information to policy makers and the public.*"

Attention to quality issues and uncertainty is not new for the EEA [29] [5] [30], and it has increased as a result of public concerns over the quality of environmental studies [31], which triggered more explicit and systematic treatment of uncertainty in sustainability assessments. Because of the uneven distribution of uncertainty treatment across the EEA knowledge chain (i.e. the Monitoring-Data-Indicator-Assessment-Knowledge framework), and the progressive shift in attention towards solution-orientated, systems and sustainability assessments, quality concerns have increased. For instance, uncertainties of less technical nature, and relevant to world-views, values, and trade-offs have come to the fore which requires to engage more prominently with civil society and multiple stakeholders, broadening the already ample spectrum of the EEA institutional partners.

Developing the State and Outlook of the European environment integrated assessment report 2020, the EEA has initiated a process to ensure that the structure, and quality of the knowledge base, including multiple sorts of uncertainty, are critically identified and communicated.

[2] https://www.eea.europa.eu/about-us

To this goal, the assessment process has been set-up and articulated according to the following steps: stock-taking of practices and approaches in academia and among similar institutions; awareness raising through workshops; and pragmatic application to the SOER context. It has been deployed to foster diffusion of knowledge and stimulate development of attitudes and skills among EEA staff involved in the drafting of the assessment.

The main outcome resulted in a guidance document in the form of a checklist for authors, aimed at facilitating assessment and communication of overall robustness of findings in SOER thematic chapters. The approach, tested and refined through interactions among EEA staff members, has been largely inspired by guidance for uncertainty assessment and communication developed in the Netherlands [32][33][34][35][36], one of the first applications of PNS as a reflexive tool for knowledge quality assessment in public institutions [31].

Overall, the thematic authors were guided toward the identification of uncertainties pertaining to framing, consistency between knowledge base and the problem, as well as on more technical aspects. To facilitate further interactions and applicability, special emphasis has been put on identifying aspects such as soundness and completeness of the knowledge base, main limitations and degree of expert judgement involved. In order to increase the relevance and visibility of the outcomes, overall reflections on the underpinning knowledge base and its robustness have been included in thematic summary tables, as a complement to environmental trends and prospects.

Aspects related to framing and pertinence of the knowledge base have been left to the main text of the assessment, and to the processes of interaction and feedback with institutional stakeholders. The uncertainties characterising systemic, forward-looking and solution-orientated aspects of the assessment, were the most difficult to deal with. Combining diverging perspectives within an overarching narrative has implied choices, simplifications and even exclusions, limiting the ability to fully describe complex, uncertain and ambiguous aspects of sustainability challenges and responses.

Overall, while unable to respond to all possible concerns regarding practice in a boundary organization [37] (e.g. epistemic authority and extended peer community) the next edition of the SOER report is expected to reflect an improved understanding of quality and uncertainty issues as well as improved transparency in their communication. Though incremental, this can be regarded as an important advancement. Also, the spill-over effect that EEA's products and

approaches have in framing environmental and sustainability challenges in Europe should not be underestimated, also for what concerns countries reporting across the European environment information and observation network (Eionet).

Second lens, Controversy studies

The lens

Science and society increasingly face endless controversies on issues such as e.g. the desirability of genetically modified food, the use of geoengineering to fight climate change, or the relative importance of interacting causes in explaining observed patterns of pollinator decline. More and better science on these risks will not necessarily close the controversies [38].

Additionally, the phenomenon of scientific dissent and controversy tends to be under-addressed in existing analyses of uncertainty and quality at the science-policy interface, where the prevailing narrative tends to exalt consensus, often used instrumentally to adjudicate a political debate [39].

This lens suggests a systematic mapping and analysing of how societal interests and conflicts co-shape the ways in which evidence is produced, communicated and used, how uncertainty is dealt with, how institutionalized styles of reasoning on evidence and regulatory frameworks co-define whose evidence counts and what style of scientific reasoning [40]. In-depth insight is thus obtained in the anatomy of scientific dissent and the surrounding controversies. This can in turn be used to anticipate conflict and manage it proactively, improve uncertainty communication and enhance the quality and transparency of scientific assessments. This lens acknowledges its debt to critical discourse analysis and to the practice of 'constructive deconstruction' typical of a PNS style of analysis. In the integrated set of lenses proposed in this work this particular lens takes the phenomenon of scientific controversy as the object of the analysis, as opposed to an accident in the treatment of a controversial case. It tests the quality of existing narratives when scientific dissent, i.e. the co-existence of a plurality of tenable but conflicting scientific interpretations of the same body of evidence, is taken as part of the definition of the problem. As noted by Beck [1]

> "--- from the experts and the fundamental controversies they have fought out (or not fought out) one can learn how unwelcome results can be blocked professionally (by methodological criticism, for instance)."

The lens in action: Chemicals pollution and biodiversity and ecosystem services: the case of neonicotinoid insecticides and entomofauna collapse (insectageddon)

This case deals with the parallel increase of honeybee disorders reported in many European countries (e.g. France, Belgium, Italy, Portugal, Germany, Netherlands, UK, Greece) and in American apiaries [41][42] and the global declines in wild pollinators [43], and insects in general [44], which has received considerable mediatic attention [45][46] and is the subject of an intense controversy involving important players in the agrochemical sector. The available evidence correlates overall insect decline to intensive agriculture with systemic neonicotinoid insecticides as the most problematic class of agrochemicals.

Neonicotinoids - the globally most widely used and fastest growing class of insecticides, and whose residual we now regularly ingest with food and vegetable [47], are very high on the list of persistent organochlorine pollutants of emerging concern and are considered to be one of the key drivers of this global collapse of insect populations [48][49]. The collapse has a number of repercussions including loss of biodiversity and impairment of ecosystem resilience, also outside of the insect realm, and poses a global risk to insect-mediated ecosystem services such as pollination, soil and freshwater functions (decomposition of organic matter and nutrient cycling), fisheries, biological pest control. Such insect-mediated ecosystem services are essential for ecosystem functioning and global food security.

In February 2018 EFSA published its long-awaited new risk assessment (https://www.efsa.europa.eu/en/press/news/180228) and concluded that most uses of neonicotinoid pesticides represent a risk to wild bees and honeybees. These new conclusions update those published in 2013, after which the European Commission imposed controls on use of the substances. For the new assessments, which this time cover wild bees – bumblebees and solitary bees – as well as honeybees, EFSA's Pesticides Unit carried out an extensive data collection exercise, including a systematic literature review, to gather all the scientific evidence published since the previous evaluations. The risk to bees varied depending on the crop and exposure route, but "for all the outdoor uses, there was at least one aspect of the assessment indicating a high risk."

On April 27, 2018, the European Commission decided to impose a ban on three of the six neonicotinoids that are allowed in Europe, after managing to achieve the necessary qualified majority among EU member states. All outdoor uses of three active substances use in plant protection products (Bayer's imidacloprid and clothianidin, and Syngenta's thiamethoxam) are be banned, and use is only permitted in permanent greenhouses [50].

This does not at all solve the problem of widespread pollution with this class of persistent chemicals in Europe because:

- the use of these 3 chemicals as plant protection products in greenhouses continues and the also large scale use of these three chemicals as biocide in cattle breeding, treatment of fleas and flies in pets and treatment of transport vehicles (containers, ships, trucks, cattle-trucks, etc.) continues to pollute surface waters and soils from where the toxic substances will continue to translocate to pollen and nectar of wild plants.

- after the 2013 and 2018 bans, for many applications there has been be a shift to the 3 other neonicotinoids that are still allowed in Europe, thiacloprid, acetamiprid and sulfoxaflor.

Based on a conclusion by EFSA that thiacloprid is not safe for human health [51], on 22 October 2019, the EU decided not the renew the authorization of thiacloprid, meaning that after April 2020 thiacloprid is no longer allowed for outdoor use in agriculture.

Critical discourse analysis and institutional analysis have been used in [52] to interpret the controversy. The case study revealed the existence of two ‘discourse coalitions’:
(1) One, represented by Bayer, AFSSA and partially the Ministry, make reference, in their public discourses, to all honeybee losses (everywhere in France, in all seasons). They do not particularly focus on sunflower and maize areas, or on the specific signs observed by beekeepers in these areas. However, they make reference to other potentially causal factors in arguing for a non-causal relationship between imidacloprid and honeybees.
(2) The second, represented by beekeepers and public scientists, affirm the determinant role of imidacloprid in honeybee losses found in sunflower and maize areas, all stating that many causes, among which diseases must require particular attention, can lead to honeybee losses all over France. Some beekeepers also pointed to the sublethal action of imidacloprid and to its possible synergic effects with diseases.
Specific to the case, it identified the following sources of controversy:

- Lack of shared definition and quantification of the signs
- Lack of specialist knowledge on honeybees
- Patterns of strategic discursive practices: part of the debate on ‘multi-causality versus imidacloprid was due to confusion, to strategic discursive practices and to passionate attitudes regarding persons from the ‘opposite camp’. The experts themselves are trapped in the socio-political position associated with an argument and stop thinking critically about its plausibility.

Based on this analysis [52] six new knowledge quality criteria are proposed that can assist in assessing the information communicated in an argumentative public process:

1. reliability of the information – it must be based on all available scientific knowledge;
2. robustness of the information – it must take into account criticism;
3. use of the information produced by other stakeholders;
4. relevancy of the arguments for issue under debate;
5. logical coherence of the discourse;
6. legitimacy of the information source.

Further, our findings deepen the understanding of the relationships between the social, economic, and institutional stakes of the actors involved in the debate and their strategies of 'creating uncertainty' [53].

Third Lens, sensitivity auditing

The lens

Sensitivity auditing (not to be confused with sensitivity analysis [54]) addresses models and indicators when used at the science-policy interface. It includes and extends global uncertainty and sensitivity analyses and checks for rhetoric or ritual use of mathematical modelling. Sensitivity auditing is especially suited to deconstruct dubious quantifications, reframe contested issues and possibly defuse controversies. Given the omnipresence of quantification in environmental and sustainability assessment, this lens plays the role of fact checking, looking specifically at the quality (both normative and technical) of numbers and their production. Sensitivity auditing, as distinct from uncertainty quantification and sensitivity analysis, is extensively described and commented both in the European Commission guidelines for impact assessment[55] and in a more recent report of the science academies on science for policy (SAPEA [11]).

Uncertainty quantification involves a propagation of the uncertainties of the input factors and assumptions throughout the model, all the way up to the model-based inference. Scholars from various disciplines [56], [24] have noted that a modeller might resort to 'massaging', e.g. arbitrarily reducing or inflating, the uncertainty depending upon whether one wishes to reinforce or to invalidate a model-based assessment.

A global quantitative **sensitivity analysis** [54] explores systematically the space of the input factors [57] in order to ascertain which input factor or assumption drives the uncertainty, and which is instead uninfluential.

Scientific evidence presented in support to policy is likely to be conflictual and disputed. In upholding their peculiar knowledge claims, all sides in disputes may be guilty of inappropriate generalizations, hidden value judgements and misrepresentation of the other parties' arguments. In these situations, a model-based assessment may be vulnerable to the choice of the model itself, to the institutional or industrial setting where the model was developed, and to the framing of the study. This is addressed by **sensitivity auditing's** seven points checklist [58]:

- **Rule 1:** 'Check against rhetorical use of mathematical modelling'; are results being over-interpreted? Is the model being used ritually or rhetorically?
- **Rule 2:** 'Adopt an "assumption hunting" attitude'; this would focus on unearthing possibly implicit assumptions.
- **Rule 3: '**Detect pseudo-science'; this asks whether uncertainty has been downplayed, as discussed above, in order to present results in a more favourable light.
- **Rule 4:** 'Find sensitive assumptions before these find you'; this is a reminder that before publishing results the analysis of sensitivity should be done and made accessible to researchers.
- **Rule 5:** 'Aim for transparency'. This rule echoes present debates on open data, and of the need for a third party to be able to replicate a given analysis.
- **Rule 6:** 'Do the right sums'; the analysis should not solve the wrong problem – doing the right sums is more important than doing the sums right. This rule is about asking whether the given quantification is not neglecting important alternative ways to frame a given example.
- **Rule 7:** 'Focus the analysis on the key question answered by the model, exploring holistically the entire space of the assumptions'. An important implication of this rule is that a model cannot be audited for sensitivity once and for all, but needs to be re-audited in the context of each specific application of the model.

Recent applications of these methodologies were in the field of models for the costing of climate change [59], the ecological footprint [60], GMO [61], the OECD-PISA studies [62], epidemiology [63], and the food security case described here [21]. An extension of rule 6 about how to characterize and evaluate the framing of an issue is quantitative storytelling [64][65]. Sensitivity auditing is part of an ongoing reflection on ethics of quantification [66][67].

The lens in action: Feeding the planet in 2050

A study [68] has suggested that improving in agricultural techniques and adopting better dietary styles will lead to producing more food on less land, as to feed, in 2050, ten billion people. The scenario proposed in the study frames the world as suffering from obesity in the developed countries and hunger in developing countries because of the inappropriateness of the global food production system. The proposed solutions aim at better diets and the contextual reduction of common diseases such as obesity and diabetes. This is achieved thanks to the world agriculture reducing the production of cereals, starches, oils, fats, and sugars in favour of that of fruit and vegetables.

The policy mix advocated to meet these goals includes consumer education, better food literacy and cooking skills, taxing unhealthy food, limiting the use of antibiotics, mitigating greenhouse gas emission in agriculture, reducing the US corn subsidy, and realizing better storage facilities in developing countries. Note that all measures but the last are to be implemented in developed countries. Sensitivity auditing notes instead [21]:

- The study proposes 9% reduction in land use, and 1% yearly improvement in production between now and 2050, when population is assumed at 10 billion. Doing the computations, it results that the same amount of food per capita is produced in 2050 as today. Hence the future scenario does not generate more food per person on average.
- Assuming that agriculture can grow on average by 1% between now and 2050 implying neglecting the existing and projected stress on soils.
- Will people desire to adopt a less cereal-and-meat-based diet? In 2050 there will be a higher share of adults given the forecasted reduction in fertility, and adults need more calories than children. Additionally, existing literature points to an increasing consumption of meat in developing countries.

- As per the role of education, the study [13] presents smoking as an example of how better policies and education may lead to better habits. In fact, while smoking decreases in developed countries it increases in many developing ones. Developing countries have weaker regulatory systems, less capable to counteract food lobbies, so that the desired policies are predicated on a global improvement of governance.

An alternative framing of the issue could consider that asymmetries in the political power of trade patterns are at the root of the issue of diet quality in several areas of the world, a phenomenon that has been recently named 'caloric unequal exchange'. Although the export from Latin America and the Caribbean to the rest of the world are more expensive than those imported, the ratio of the two is decreasing with time, with the global south subsidizing the diet of the global north.

Hence the proposed scenario applies a developed world perspective, substituting a political problem - power asymmetry, with a technical one - a mismatch between what the world needs for everyone to enjoy a nutritious diet and what the world is actually producing.

Fourth lens, Bioeconomics

The lens

Bio-economics was suggested by Nicholas Georgescu-Roegen [69] as a necessary complement to neo-classical economics in order to avoid the dangerous hypo-cognition determined by its simplistic framing of the issue of sustainability. Bioeconomics analyses in a transdisciplinary way the interaction of the socio-economic process with the ecological processes in which the society is embedded describing the metabolic pattern of socio-ecological systems across different levels and dimensions. In particular, the accounting method of Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) identifies and characterizes the factors determining the "feasibility" (e.g. existence of external biophysical constraints when looking at the compatibility of processes taking place in the technosphere with processes taking place in the biosphere), "viability" (e.g. existence of internal biophysical and economic constraints affecting processes inside the technosphere) and "desirability" (e.g. stakeholders' norms and world views determining the stability of institutional settings) of the metabolic pattern. In the context of the present integrated set this particular lens provides an additional layer of fact checking (also here both technical and normative) based on the discipline of bioeconomics. It can unencumber the

public discourse from fantastic scenarios which simply 'don't compute' in light of bioeconomic analysis.

The lens in action: A biophysical analysis of the circular economy

Neo-classical economics portrays the economic process as a self-sustaining merry-go-round between production and consumption of goods and services, in which the crucial role of the environment in providing primary inputs and recycling wastes is simply not considered [70]. Therefore, we can say that the idea of 'circular economy' is a direct legacy of a systemic adoption of economic narratives when framing the sustainability predicament. Two considerations based on biophysical analysis can be used to show the fundamental challenges that the concept of circular economy entails when ecological constraints are taken into account and confronted with an economic paradigm advocating for infinite growth.

1. In empirical terms – the industrial revolution has been "the big linearization"

Food Security - Since 1970 the size of human population has doubled whereas the production of food has more than doubled (because of the double conversion to produce animal products). The need of continuously boosting food production for a growing population (demographic pressure entails less land per capita) using less farmers in the work force (the bio-economic pressure associated with massive urbanization) has implied the abandonment of traditional and ecological friendly methods of agricultural production (where nutrients were naturally re-circulated). The progressive move to the paradigm of industrial agriculture implies that nutrients and other inputs are based on massive injection of fossil energy [71]. The pace and density of natural deposition of nitrogen in the soil would not make it possible to achieve average yields of 7-10 tonnes of grain per hectare – what is achieved by modern agriculture in developed countries. Even more important is the constraint on the limited size of the work force in agriculture in developed countries. To achieve a productivity of labor in the order of thousand kg of grain/hour modern agriculture is based on high external input mechanized monocultures.

Energy Security - The same linearization of flows took place in relation to energy security when moving from biomass to fossil energy. The supply of energy to modern society is obtained by linear flows coming from stocks of fossil energy providing a density and a pace of energy flows which is orders of magnitude higher than the one obtainable when using biomass produced by closing nutrient cycles [72]. The industrial revolution implied a dramatic switch from an exploitation of renewable energy sources – flows of biomass and

other sources provided by natural processes – to non-renewable energy sources – fossil reserves accumulated by natural processes for millions of years.

When considering biophysical processes adopted by modern societies to guarantee food and energy security we can conclude that the major boost in productivity of both land and labor have been obtained because of a clear linearization of flows. Relying on nature to "close the loop" will imply a major reduction in the productivity of production factors (a green degrowth).

2. In theoretical terms - the elephant in the room: the entropic nature of the economic process

What is circulated in the economy of developed countries? – A paper entitled "how circular is the global economy" published by Haas et al. [73] provides clear evidence that both the economy of the world and that of developed economies (they use the assessment of the European Union as example) is not circular. The analysis of the material flows in Europe, for the year 2005 shows that 52% of the material input (without considering water) is composed of either food or energy inputs: these are two flows that by default are degraded in an irreversible way and that therefore cannot be recycled. Another 45% of the material input is composed of construction materials that are incorporated in the societal fund elements in the form of buildings and infrastructures. This leaves a 3% of material goods that could be recycled. Recycling rates of these materials differ substantially among materials and countries [74], but the level of recirculation of the materials in consumable and durable products is generally low – the average over the mix is well below 40% [75].

The entropic nature of the economy - However, it should be noted that there is an elephant in the room missed by the analysis of material flows given above: the key role of water in making the metabolic pattern of modern economies possible. Water is the engine used by Gaia to keep life on our planet and it is essential in preserving the health of ecosystems. The contribution of the water cycle, totally outside of human control, both in energy and matter terms, is orders of magnitude larger than the material and energy flows metabolized by society [76]. Using a very conservative estimate of 300 tonnes of water evapotranspirated per tonne of biomass produced and consumed by society the water used by natural processes to produce human food is more than 100 times larger than the solid material flow

metabolized by society. When considering also this element we can conclude that Georgescu-Roegen was right, the economy is an entropic process which is based on the availability of primary sources and primary sinks provided "free-of charge" by nature. Natural processes are free, but unfortunately, they have a pace and a density that do not match the required productivity of the production factors expected in developed economies.

Fifth lens, Ethics of science for governance

The lens

This lens tackles the integration of ethical concern in the way science is produced and deployed in support to a given policy into the assessments of progress in science and technology towards a sustainable future. Ethical concerns may pertain the integrity of the science, the ethical conduct of research experiments, and the social responsibility in science and technology - now addressed under the term Responsible Research and Innovation (RRI). All of these concerns refer to underlying values and basic ethical issues. The use of methodologies such as ethical matrices, value mapping and value atlas can help to ensure that both fact-based and value-based elements of a study can be properly contextualised. The purpose of this lens in the economy of the present work is – again – a quality check of the proposed narratives, to debunk those which are evidently and fatally based of the normative and cultural frames of the observer and not of the observed. It seeks alignment with social values and contributes, thus, to trust among the knowledge producers and knowledge-users.

The lens in action: The variety of values of seafood production and value chains

Seafood is globally the most traded commodity, and it is securing an ever-increasing market share in industrialised countries. Because of its importance, coupled to both highly positive potentials (food security: more high quality healthy, safe food etc.) and to negative scenarios (depleting the ocean resources, polluting coastal zones, decreasing quality of food, fish diseases, etc.), seafood is on everybody's agenda. The prospect of a blue (sustainable maritime) economy seems like one of the few promising development paths which can capture the minds of people, very much like the Klondike of the past. Yet, closer inspection reveals some major challenges.

First of all, ecology: expanding the production of food from the oceans implies major interventions and changes in our ecosystems. This seems also relevant for future aquaculture

developments. Given that many of our marine ecosystems in many parts of the world are highly vulnerable already, and given far-reaching protection goals of these ecosystems, managing significantly increased seafood productions without polluting effects or other potential harms (fish diseases, diminishing stocks, and so on) appears a delicate task. All such interventions will generate societal value conflicts and intense political debate.

Secondly, socio-cultural challenge: growth also implies huge societal efforts and new infrastructures to integrate the increased novel food production into ordinary market mechanisms, as seafood is to a large part traded in long value chains across the globe. Local market supply is still the rule in developing poor countries, but in industrialised countries, as e.g. Europe, globally traded seafood dominates the market. What can be seen so far is that ethical concerns seem to gain more ground among consumers and should perhaps be included in our policies [77].

Thirdly, divided science: in regard to fisheries we see that managing fish stocks in our oceans seems a permanent unfinished business, with some scientific assessments pointing in one direction and political multi-national decision-making on quota going in another direction, always with higher allowances. Precaution and short-term economic gains seem at cross-purposes to the detriment of the fish stocks.

The situation concerning seafood as combining both fisheries and aquaculture shows all the typical signs of post-normality (Lens 1): facts are uncertain, values disputed, decisions urgent and decision stakes are high. Even the most basic depictions of the state-of-the art, of the problems, and of the option space are so deeply value-infected that they only partially overlap. Controversy surrounds the available catch data due to the importance of illegal or unreported activities [78] to the effect that global assessments differ.

Stock assessments (be they global or local) are beset with inherent uncertainties, and the very same methods used to arrive at such assessments vary significantly.

Similar conflicts plague the aquaculture community and marine scientists. What is the environmental and resource impact of current aquaculture? Why is there widespread consumer scepticism against aquaculture products? How do we assess the potential of future aquaculture development, be it on land-based or integrated multi-trophic systems? Here we find the same or similar value-infectedness as with the fisheries. For some scientists, the ecological accounting of aquaculture bespeaks extensive small-scale production units, regulated by strict certification schemes and legal regimes. For others, intensive large-scale

production is an obvious need in view of the need to feed an increasing global population, and to meet expectations of the global markets.

To complicate an already complex picture the possible introduction of genetically modified production fish in aquaculture needs to be considered [79], with its ethical implications.

As the value chain of seafood is to a very large extent long and global, knowledge about similarities and differences in the values and ethical principles of the involved cultures cannot be excluded. Ongoing research in practical ethics [80] involves the creation of value atlas [81], aimed at gathering the most significant data, surveys and studies on attitudes and values related to an important development path of economy, science and technology. Empirical research to this end may utilise value-mapping as exemplified in a study of aquaculture in Asia [82]. Ethical considerations are also addressed via ethical matrices [83][84] where chosen ethical principles are specified in regard to the interests of different stakeholders.

Assume the aim is to assess the ethical aspects of a certain genetic modification of a fish species for food production in a region. Following the ethical matrix approach, the first task would be to identify the relevant stakeholders, e.g. small-scale producers and consumers. Another requirement would be to identify potentially affected organisms and their components of the environment, for example fish and biota. A proper set of ethical principles needs then to be established: justice/fairness, dignity/autonomy, the obligation to do no harm and the goal of doing good, for example. Once a common understanding of these principles is ensured, it is important that the principles are specified for each interest perspective. The result is an ethical matrix that represents the starting point of the ethical assessment, here from [85].

Table 1

Ethical matrix for gm-fish:	Do avoid doing any harm	Do try to do some good	Dignity / autonomy	Justice / fairness
Small producers	Dependencies on nature and corporations	Adequate income and work security	Freedom to adopt or not to adopt	Fair treatment in trade
Consumers	Safe food	Nutritional quality Food security	Respect for consumer choice (labelling)	General affordability of food product

Treated fish	Proper animal welfare	Improved disease resistance	Behavioural freedom	Respect for natural capacities (telos)
Biota	Pollution and strain on natural resources	Increasing sustainability Improved resilience	Maintenance of biodiversity	No additional strain on regional natural resources

599

600 This test case shows how facts and values are deeply intertwined when discussing seafood
601 production and consumption. The topic of seafood (as assumedly the topic of food in general)
602 should be connected to deep seated value issues, and these values should be made explicit.
603 This applies equally to the value-infectedness of most of the scientific expertise dealing with
604 this topic. Presentations of relatively complex issues like the state of the fish stocks in the
605 oceans or the prospects of aquaculture developments should at the outset be designed to
606 present a range of different viewpoints and data entries (Value Atlas). One of the dangers is
607 the fixation of ethical assessments to a single tool of practical ethics (e.g. the ethical matrix),
608 in the belief that all relevant aspects of the complex issue have indeed been captured. We
609 surmise that this happened, for instance, in the field of medical ethics, where one analytic
610 tool gained prominence over all others [86]. Ethical issues – their normative nature
611 notwithstanding - are always highly contextual and to a certain extent culture-dependent, at
612 least in terms of social acceptance. Openness to different value-landscapes and plurality in
613 the ethical toolbox are a pre-requisite for avoiding that in-built bias of the analyst
614 significantly skews the assessment. Finally, conflicted topics regarding seafood (or similar
615 topics) should be presented with entries that can guide the user to further ethical reflection
616 and include as much relevant data and knowledge as possible.

617

618 ## Sixth lens, non-Ricardian economics

619 ### The lens

620 While non-Ricardian economics may sound as a term of the craft, it is gaining traction in the
621 context of the present climate of yet timid revision of economic theory [87]. It denotes the
622 economic theories which refute Ricardo's theorem of comparative advantage and decries its
623 momentous implications in the present mostly neoliberal institutional arrangements, as
624 discussed below. A relevant work in this context is "*How rich countries got rich and why*

poor countries stay poor" [88]. First published in 2007, it is now translated into more than twenty languages, confirming that the transition is within our Zeitgeist just alluded to.

Even environmental studies need to rely on an economic paradigm, implicitly or explicitly. What would happen if the prevailing paradigms were flawed? We argue that today's mainstream economic theory is flawed for a number of reasons, and this section lists some of them [88]. During the Enlightenment the establishment of taxonomies – as in the case of Linnaeus – created order. Similarly, in economics, there were theories of 'good' and 'bad' trade for a country [89]. A key feature of today's economic theory is the lack of any taxonomy. A simple taxonomy of three different types of economic activities would explain the old idea of 'good' and 'bad' trade, and it will also assist us in distinguishing where technology optimism is appropriate and where technology pessimism seems most appropriate:

1. Activities subject to *diminishing returns to scale*, i.e. when one factor of production is limited by nature (agriculture, mining, fisheries). This makes economics into a 'dismal' science because increasing production yields increasingly lower production. These activities are subject to perfect competition, e.g. increased productivity tends to lower prices to the consumer rather than increase profits and wages to the producers.

2. Activities subject to *constant returns to scale*. Traditional service sector, professions like barbers and house painters.

3. Activities subject to *increasing returns to scale*. Here each new unit of production lowers the costs of production, allowing for imperfect competition by creating high barriers to entry into the industry.

Paradoxically, if one looks at the history of economics, the present orthodoxy – which neglects these fundamental distinctions, represents a minority view in a secular perspective of human development [90][91] where nations' strategy has been to manufacture/industrialize first, and open to the market later. Exporting raw materials in order to import manufactured goods was for centuries seen as 'bad trade'.

Thus, this lens argues that sustainability is hampered by the prevailing, neoclassical, free-trade-based paradigm which de facto blocks developing countries' path to development based on manufacture of increasing returns goods and locks them into activities exploiting nature under diminishing returns.

The distinction between increasing and diminishing returns is crucial in understanding the difference – in energy production, between unsustainable extraction e.g. of oil and coal versus the sustainable manufacturing of harvesting energy from wind and sun.

The quality checks offered by this lens are crucial – no transition or development is possible based on a flawed economic theory.

The lens in action: Evaluating the Potential for Green Growth in a context of Technology Optimism and Technology Pessimism

This test case investigates the consequences of adopting a different economic canon to look at transitions.

The standard, neo-classical canon of economic development is instrumental in maintaining radical differences between the global North and the global South, a difference pursued by the colonial powers against their colonies since the XIX century, and based on keeping them de-industrialized [88][92]. In a world of perfect free trade, forbidden to develop their own system of manufactures and innovation, developing countries are lectured on the need to develop e.g. the right institutions - as if the right institutions could produce the successful model of economic development. We refer to this presently popular approach – focusing on the symptoms rather than on the causes of poverty – as *palliative economics* [88].

History teaches a different lesson, one where Novelty, Diversity, Scale, and Synergy and the interaction between these factors produce wealth - in a system which allows countries to dynamically pursue increasing returns activities which in turn demand the development of appropriate institutions. Applied in the restricted context of the European Union, the standard Ricardian canon is presently damaging economies of east European countries where signals of re-feudalization are appearing as a result of the destruction of their manufacture [93]. More, the present situation which advantages the developed countries is unsustainable in the long term - as the increasing number of failing states shows. From the early Italian city states until the Marshall Plan it has been understood that wealth was a result of synergies between increasing returns activities, i.e. industry and manufacture. The fact that the world's most efficient farmers - in the EU and US - still need subsidies and protection testifies to this.

The direct application of these concepts to the energy futures [94] suggest adopting renewables and cleantech, not just for emission reduction, but because these embody

technological change, manufacturing, learning curve effects, and are thus capable of capturing increasing returns. In contrast, fossil fuels are a typical diminishing returns activity.

Putting renewable energies at the core of a country's industrial policy will drive down costs as the country moves along the learning curve. As costs decline, so the market expands and even more specialized activities can be developed. These in turn enhance productivity and lead to further market expansion, further fall in costs, and further specialization within a well-tested capitalist system of "circular and cumulative causation".

We argue that the energy choices currently being made by China and India appear to conform to this reading, whereby China might be the first country to lead the path to an expansion of the market for renewables and reduction of the costs made possible by the increasing returns. With renewable power energy can be harvested, which at present is only practiced in hydropower, while with fossil fuels it needs to be extracted under diminishing returns. This path to transition based on an industrial policy focusing on renewables appears much more promising and better supported by evidence than generic calls for "more innovation" or for taxes on carbon-intensive activities. As for the past, a period of protection will be needed to let these "infant industries" gain speed. At present, the case for renewables is opposed by vested interest of the fossil fuel sector [95] as well as by the so called "neutral" economists who insist that markets should be allowed to function "free of interference". Yet the example of China show that state support can be in the long term successful, repeating for energy what was the development trajectory followed by all developed countries in manufacturing [92][88][93].

The lenses together

To show where integrating the lenses leads, an overview (Table 2) describes the role and expected contribution of each lens to the enhancement of key attributes of integrated assessments: saliency, legitimacy and credibility.

Table 2 Role of each of the lenses in enhancing integrated assessments. The focus is on main attributes according to EEA's perspective: salience, legitimacy and credibility [5]

[Table 2 here]

Additionally, to show an example of all lenses in action, we go back to the example of food security discussed in the third lens. In this test case [21] we used sensitivity auditing to reach the conclusions that the numbers produced in the context of a research on food security [68] didn't stand, and that the overall narrative of this style of problem solving – which one can name as techno-optimist, replaced a political problem – global inequality, with a technical problem – the mix of agricultural goods produced. We now revisit the same case using all lenses.

- The global system of trade bears a fundamental responsibility for diet quality in several areas of the world, a phenomenon that has been recently named caloric unequal exchange [96], with the global south subsidizing the diet of the global north. Our economic non-Ricardian lens suggests that poor countries are kept poor by the interdiction to develop a manufacturing sector. For this lens even the same millennium development goals are problematic, as they represent an attempt to cure the symptoms – i.e. poverty, rather than its cause, for which international institutions such as the Word Bank and the International Monetary Fund bear important responsibilities. A critique of the millennium development goals – as done in [88], implies a rather dramatic change of economic zeitgeist which we as author hesitate to predict: are we close to a moment similar to 1848, i.e. a turn away from abstract economic theories toward more relevant ones [97]? History will tell. The level of resistance associated to this type of ideological transition calls for the expertise of our controversy lens.

- The assumption that what works in developed countries, in terms e.g. of educational policies for a transition to a different diet [21], will also work in developing countries resembles the already discussed case of implanting common law in Iraq. Here the ethical lens would warn us that something is seriously wrong.

- Some of the numbers seen in food security do not resist deconstruction [21], as shown by the sensitivity auditing analysis.

- The role of genetically modified technology to achieve a new regime of food production can be seen as an imprudent use of technology, while the framing of the GMO debate in terms of alimentary safety has been exposed as incomplete, forgetful of the political debate in society on the desirability of the new technologies and on the configuration of power the technology promotes [98]. Bioeconomics and Post normal

science offer some clarity here. For example, a simple fact checking on biophysical quantities (e.g. yields per hectare) shows that the promise of higher yields associated with the adoption of GMO crops is simply not true [99]. It is indicative that popular resistance to GM food has focused more on the ethical issues than on the risk issues [100][101]. The Precautionary Principle has appeal because of its ethical underpinnings [102][103]. Being explicit about this and addressing the ethical challenges should be the norm rather than the exception [84], side-lined to the social sciences and philosophy.

- The idea of precision or intensive agriculture can be seen as an example of linearization of the complexities of the top-soil system. Even here PNS' appeal to prudent technology and bioeconomics' careful accounting of what is feasible come to the fore.

While reasons of space prevent us from reproducing this 'all lenses' approach to all narratives discussed here, we hope that the gist of the school has been given.

Conclusions:

The ideas that something is lacking in existing stories about sustainability and transitions is a common topos. To make just two examples among many, for Sheila Jasanoff [15] existing transition discourses gloss over the uncertain relationships between prosperity and sustainability and do not address the elementary principle of social justice on how the burden should be shared. For Jeremy Lent [14] our collective action to enact transitions to a more sustainable future is hampered by the lingering of unhelpful metaphors, mainly that of 'man as master and possessor of nature', and about 'nature as a machine'; thus, if nature is a machine, I can fix it by geoengineering its climate, manipulating the genes of its species, and solve with science and technology the problems which science and technology have created.

We continue in this tradition of critique, with a somewhat more specific question:

1) **To what extent does the method, or the discipline, influence the prescription of the analysis?** As stated in the title, the technique is never neutral. Our present is populated with several stories – some of which touched in this article, whose existence is permitted by the chosen methodological and disciplinary configuration. Challenging this configuration, e.g. replacing neoclassic economics with bioeconomics and non-Ricardian economics; a neo-positivistic vision of the role of science and technology with a post normal one; audacious quantifications with

781 responsible ones; and looking at the present with its conflicts as the place where
782 different values are plausible and legitimate, may result in novel insights and
783 narratives. We have zoomed in on a set of approaches or tools which we call lenses,
784 with the idea that - applying these together, a richer picture will emerge and thus
785 enlarge the space of the possible solutions. **Wearing those lenses both implies and**
786 **produces important changes of perspective.**

787 If progress cannot be achieved by developing nations in a regime of perfect trade,
788 then what has to be changed is our global governance. If the linearized idea of nature
789 underpinning many existing risk and cost benefit analyses is replaced by the concept
790 of nature as a system of systems, as suggested by relational biology [104] and
791 bioeconomics, then many existing 'proofs' of feasibility of new technologies need to
792 be reconsidered. Looking through the existing frames and metaphors in search of
793 forgotten or ignored knowledges may open the space to other possible solutions, and
794 unmask the improper translation of a political problem into a technical one [23].
795 Insisting on notions of 'consensus' in science for policy may imply a
796 misrepresentation or a banalization of the opinion of dissenters, which may lead to
797 further radicalization, while at the same time neglecting power games and
798 relationships when high interests are at stake. Ignoring ethical and cultural
799 specificities of different publics in the global arena may lead to blunders similar to the
800 US attempt to transplant the US judiciary system into Iraq after the end of hostilities
801 [105], and so on.

802 2) **How to tackle uncertainties and ensure quality in integrated assessment for**
803 **sustainability?** We suggest that the lenses provide a convincing intellectual
804 framework for this purpose. One might look at a specific sustainability or transition
805 policy wearing the lenses and running through a checklist as:

806 - Is the framing of the problem incomplete? Does the framing include its political (as
807 opposed to technical) dimensions, or was the technique, and its numbers, used to
808 obfuscate and distract? (All lenses)

809 - How robust is the process adopted to produce quantified information? Whose
810 evidence counts? Have all affected actors been identified? Who are the
811 winners/losers? Who are the excluded? (PNS, sensitivity auditing)

- Does the transition take into consideration the systemic property of the problem? (Bioeconomics)
- Is the transition compatible with the ethos and the culture of the involved publics? Are there conflicts in the value-landscapes of these cultures? Which roots do these have? (Ethics)
- Are prudent, controllable technologies employed? (PNS)

The reader will have noticed that this approach has many elements of a *via negativa*, like when in theology we renounce defining God but describe what God is not. This approach is particularly apt to deconstruct ineffectual or rhetorical narratives. This is not an accident. As argued by Nassim Taleb [106] our societies are affected by a 'positive' bias; they demand from the experts what needs to be done – and nobody gets elected for admitting that a dense web of trade-offs and conflicting interests makes any political choice of a certain importance a difficult affair. Yet, we argue that 'what to avoid' is perhaps more important than 'what to do'. Abandoning unfruitful paths makes more resources available for plausible ones. As noted by the same Taleb, one way of winning is by not losing.

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References

[1] P. U. Beck, *Risk Society: Towards a New Modernity*. Sage Publications (CA), 1992.

[2] J. H. Spangenberg and L. Polotzek, "Like blending chalk and cheese," *RWER Spec. issue Econ. Ecosyst. | Real-World Econ. Rev. Blog*, no. 87, pp. 196–212, 2019.

[3] United Nations Environment Programme (2007), "Global Environment Outlook GEO-4: environment for development," 2007.

[4] M. Kowarsch, C. Flachsland, J. Garard, J. Jabbour, and P. Riousset, "The treatment of divergent viewpoints in global environmental assessments," *Environ. Sci. Policy*, vol. 77, pp. 225–234, Nov. 2017.

[5] N. . Eckley, D. . Stanners, and D. Gee, "Designing effective assessments: The role of participation, science and governance, and focus, Environmental issue report n. 26.," 2001.

[6] A. Benessia *et al.*, *Science on the Verge*. Arizona State University, 2016.

[7] Z. Kovacic, R. Strand, and T. Völker, *The Circular Economy in Europe: Critical Perspectives on Policies and Imaginaries*. Routledge, 2019.

[8] M. Giampietro, "Perception and Representation of the Resource Nexus at the Interface between Society and the Natural Environment," *Sustainability*, vol. 10, no. 7, p. 2545, Jul. 2018.

[9] U. Felt *et al.*, *Taking European knowledge society seriously, Rep. N. 22700*. Office for Official Publications of the European Communities, 2007.

[10] S. Rayner, "Uncomfortable knowledge: the social construction of ignorance in science and environmental policy discourses," *Econ. Soc.*, vol. 41, no. 1, pp. 107–125, Feb. 2012.

[11] Science Advice for Policy by European Academies, "Making sense of science for policy under conditions of complexity and uncertainty," Berlin, 2019.

[12] L. Winner, *The whale and the reactor : a search for limits in an age of high technology*. University of Chicago Press, 1989.

[13] European Commission, "Implementation of the Circular Economy Action Plan," *Final Circular Economy Package*, 2019. [Online]. Available: http://ec.europa.eu/environment/circular-economy/index_en.htm.

[14] J. R. Lent, *The patterning instinct : a cultural history of humanity's search for meaning*. Prometheus Books, 2017.

[15] S. Jasanoff, "Just transitions: A humble approach to global energy futures," *Energy Res. Soc. Sci.*, vol. 35, pp. 11–14, Jan. 2018.

[16] Anne Fremaux and J. Barry, "The 'Good Anthropocene' and Green Political Theory: Rethinking Environmentalism, Resisting Eco-modernism," in *Anthropocene Encounters: New Directions in Green Political Thinking*, ResearchGa., 2019.

[17] V. Eswaran, "The case against techno-pessimism," *Politico.eu*, 2019.

[18] R. Strand, A. Saltelli, M. Giampietro, K. Rommetveit, and S. Funtowicz, "New narratives for innovation," *J. Clean. Prod.*, vol. 197, pp. 1849–1853, Oct. 2018.

[19] S. Funtowicz and J. R. Ravetz, "Science for the post-normal age," *Futures*, vol. 25, no. 7, pp. 739–755, Sep. 1993.

[20] S. Funtowicz and J. R. Ravetz, "The worth of a songbird: ecological economics as a post-normal science," *Ecol. Econ.*, vol. 10, no. 3, pp. 197–207, Aug. 1994.

[21] A. Saltelli and S. Lo Piano, "Problematic quantifications: a critical appraisal of scenario making for a global 'sustainable' food production," *Food Ethics*, vol. 1, no. 2, pp. 173–179, 2017.

[22] P. Gluckman, “Policy: The art of science advice to government,” *Nature*, vol. 507, no. 7491, pp. 163–165, Mar. 2014.

[23] J. R. Ravetz, *Scientific knowledge and its social problems*. Oxford University Press, 1971.

[24] S. Funtowicz and J. R. Ravetz, *Uncertainty and Quality in Science for Policy*. Dordrecht: Kluwer, 1990.

[25] A. Saltelli and S. Funtowicz, “What is science’s crisis really about?,” *Futures*, vol. 91, pp. 5–11, 2017.

[26] A. Saltelli, J. R. Ravetz, and S. Funtowicz, “A new community for science,” *New Scientist*, Jun-2016.

[27] H. W. J. Rittel and M. M. Webber, “Dilemmas in a general theory of planning,” *Policy Sci.*, vol. 4, no. 2, pp. 155–169, Jun. 1973.

[28] B. University of Florence, “PNS5 Symposium (Post normal science) - Florence 2020,” *Announcement*, 2020. [Online]. Available: https://pns5.biostatistica.net/index.php. [Accessed: 22-Aug-2019].

[29] S. Funtowicz, J. M. . Alier, G. . Munda, and J. R. Ravetz, “Information tools for environmental policy under conditions of complexity, Environmental issues series No. 9.,” 1999.

[30] EEA, “Climate change, impacts and vulnerability in Europe 2016 – An indicator-based report, Report No 1/2017.,” 2017.

[31] A. C. Petersen, A. Cath, M. Hage, E. Kunseler, and J. P. van der Sluijs, “Post-Normal Science in Practice at the Netherlands Environmental Assessment Agency,” *Sci. Technol. Hum. Values*, vol. 36, no. 3, pp. 362–388, May 2011.

[32] A. C. Petersen, P. H. M. Janssen, J. P. Van Der Sluijs, J. S. Risbey, and J. R. Ravetz, “RIVM/MNP Guidance for Uncertainty Assessment and Communication: Mini-Checklist and Quickscan Questionnaire,” *Uncertainty Analysis*. 2003.

[33] A. C. . Petersen, P. H. M. . Janssen, J. P. van der Sluijs, J. S. . Risbey, J. R. Ravetz, and H. Wardekker, J.A.; Martinson Hughes, “Guidance for Uncertainty Assessment and Communication, second edition,” 2013.

[34] J. P. van der Sluijs and A. Petersen, “Exploring the quality of evidence for complex and contested policy decisions,” *Environ. Res. Lett.*, vol. 3, no. 024008, 2008.

[35] P. Kloprogge, J. van der. Sluijs, and A. Wardekker, “Uncertainty communication : issues and good practice,” 2007.

[36] P. H. M. Janssen, A. C. Petersen, J. P. van der Sluijs, J. S. Risbey, and J. R. Ravetz, “A guidance for assessing and communicating uncertainties.,” *Water Sci. Technol.*, vol. 52, no. 6, pp. 125–31, 2005.

[37] D. H. Guston, “Boundary Organizations in Environmental Policy and Science: An Introduction,” *Sci. Technol. Hum. Values*, vol. 26, no. 4, pp. 399–408, Oct. 2001.

[38] D. Sarewitz, “How science makes environmental controversies worse,” *Environ. Sci. Policy*, vol. 7, no. 5, pp. 385–403, Oct. 2004.

[39] J. P. van der Sluijs, R. van Est, and M. Riphagen, “Beyond consensus: reflections from a democratic perspective on the interaction between climate politics and science,” *Curr. Opin. Environ. Sustain.*, vol. 2, no. 5–6, pp. 409–415, Dec. 2010.

[40] I. Hacking, “Styles of Scientific Reasoning,” in *Postanalytic Philosophy*, J. Rajchman and C. West, Eds. New York, 1985, pp. 145–64.

[41] L. Maxim and J. P. van der Sluijs, “Expert explanations of honeybee losses in areas of extensive agriculture in France: Gaucho® compared with other supposed causal factors,” *Environ. Res. Lett.*, vol. 5, no. 1, p. 014006, Jan. 2010.

[42] J. P. van der Sluijs, N. Simon-Delso, D. Goulson, L. Maxim, J.-M. Bonmatin, and L. P. Belzunces, “Neonicotinoids, bee disorders and the sustainability of pollinator services,” *Curr. Opin. Environ. Sustain.*, vol. 5, no. 3–4, pp. 293–305, Sep. 2013.

[43] J. P. van der Sluijs and N. S. Vaage, “Pollinators and Global Food Security: the Need for Holistic Global Stewardship,” *Food Ethics*, vol. 1, no. 1, pp. 75–91, Jun. 2016.

[44] C. A. Hallmann *et al.*, “More than 75 percent decline over 27 years in total flying insect biomass in protected areas,” *PLoS One*, vol. 12, no. 10, p. e0185809, Oct. 2017.

[45] G. Monbiot, “Insectageddon: farming is more catastrophic than climate breakdown,” *The Guardian*, 20-Oct-2017.

[46] “Les insectes pourraient disparaître de la planète d’ici 100 ans,” *Le Monde* , 11-Feb-2019.

[47] C. Lu, C.-H. Chang, C. Palmer, M. Zhao, and Q. Zhang, “Neonicotinoid Residues in Fruits and Vegetables: An Integrated Dietary Exposure Assessment Approach,” *Environ. Sci. Technol.*, vol. 52, no. 5, pp. 3175–3184, Mar. 2018.

[48] M. L. Hladik, A. R. Main, and D. Goulson, “Environmental Risks and Challenges Associated with Neonicotinoid Insecticides,” *Environ. Sci. Technol.*, vol. 52, no. 6, pp. 3329–3335, Mar. 2018.

[49] F. Sánchez-Bayo and K. A. G. Wyckhuys, “Worldwide decline of the entomofauna: A review of its drivers,” *Biol. Conserv.*, vol. 232, pp. 8–27, Apr. 2019.

[50] S. Michalopoulos, “Invoking science, Europe shuts the door to neonics,” *EURACTIV.com*, 2018. [Online]. Available: https://www.euractiv.com/section/agriculture-food/news/invoking-science-europe-shuts-the-door-to-neonics/.

[51] H. Abdourahime *et al.*, “Peer review of the pesticide risk assessment of the active substance thiacloprid,” *EFSA J.*, vol. 17, no. 3, Mar. 2019.

[52] L. Maxim and J. P. van der Sluijs, “Uncertainty: Cause or effect of stakeholders’ debates?,” *Sci. Total Environ.*, vol. 376, no. 1–3, pp. 1–17, Apr. 2007.

[53] D. Michaels, *Doubt is Their Product: How Industry’s Assault on Science Threatens Your Health*. Oxford University Press, 2008.

[54] A. Saltelli *et al.*, *Global sensitivity analysis : the primer*. John Wiley, 2008.

[55] European Commission, “European Commission IMPACT ASSESSMENT GUIDELINES,” 2009.

[56] E. E. Leamer, “Sensitivity Analyses Would Help,” *Am. Econ. Rev.*, vol. 75, no. 3, pp. 308–313, 1985.

[57] A. Saltelli and P. Annoni, “How to avoid a perfunctory sensitivity analysis,” *Environ. Model. Softw.*, vol. 25, no. 12, pp. 1508–1517, Dec. 2010.

[58] A. Saltelli, Â. Guimaraes Pereira, J. P. van der Sluijs, and S. Funtowicz, “What do I make of your latinorumc Sensitivity auditing of mathematical modelling,” *Int. J. Foresight Innov. Policy*, vol. 9, no. 2/3/4, pp. 213–234, 2013.

[59] A. Saltelli and B. d'Hombres, "Sensitivity analysis didn't help. A practitioner's critique of the Stern review," *Glob. Environ. Chang.*, vol. 20, no. 2, pp. 298–302, May 2010.

[60] M. Giampietro and A. Saltelli, "Footprints to nowhere," *Ecol. Indic.*, vol. 46, pp. 610–621, Nov. 2014.

[61] A. Saltelli, M. Giampietro, and T. Gomiero, "Forcing consensus is bad for science and society," *Conversat.*, no. May 12, 2017.

[62] L. Araujo, A. Saltelli, and S. V. Schnepf, "Do PISA data justify PISA-based education policy?," *Int. J. Comp. Educ. Dev.*, vol. 19, no. 1, pp. 20–34, 2017.

[63] S. Lo Piano and M. Robinson, "Nutrition and public health economic evaluations under the lenses of post normal science," *Futures*, vol. 112, p. 102436, Sep. 2019.

[64] A. Saltelli and M. Giampietro, "What is wrong with evidence based policy, and how can it be improved?," *Futures*, vol. 91, pp. 62–71, Feb. 2017.

[65] A. Renner and M. Giampietro, "Socio-technical discourses of European electricity decarbonization: Contesting narrative credibility and legitimacy with quantitative story-telling," *Energy Res. Soc. Sci.*, vol. 59, Jan. 2020.

[66] A. Saltelli, "Statistical versus mathematical modelling: a short comment," *Nat. Commun.*, vol. 10, pp. 1–3, 2019.

[67] A. Saltelli, "Ethics of quantification or quantification of ethics?," *Futures*, 2020.

[68] K. K. Badur, E. D. G. Fraser, S. Pascoal, G. Dias, and T. Zundel, "Pathways Leading to a More Sustainable and Healthy Global Food System - The Solutions Journal," 2016. [Online]. Available: https://www.thesolutionsjournal.com/article/pathways-leading-sustainable-healthy-global-food-system/. [Accessed: 05-Apr-2017].

[69] N. Georgescu-Roegen, "Bioeconomics: a new look at the nature of economic activity, Michigan Business Papers N.62.," 1977.

[70] G. M., "On the circular bio-economy and decoupling: Implications for sustainable growth," *Ecol. Econ. Submitt.*, 2019.

[71] D. Pimentel and M. Pimentel, *Food, energy, and society*. CRC Press, 2008.

[72] V. Smil, *Power density : a key to understanding energy sources and uses*. MIT press, 2015.

[73] W. Haas, F. Krausmann, D. Wiedenhofer, and M. Heinz, "How Circular is the Global Economy?: An Assessment of Material Flows, Waste Production, and Recycling in the European Union and the World in 2005," *J. Ind. Ecol.*, vol. 19, no. 5, pp. 765–777, Oct. 2015.

[74] V. Smil, *Making the Modern World : Materials and Dematerialization.* Wiley, 2013.

[75] J. Cullen, "Circular Economy: Theoretical Benchmark of Perpetual Motion Machine?," *J. Ind. Ecol.*, vol. 21, no. 3, pp. 483–486, Jun. 2017.

[76] M. Giampietro, *Multi-Scale Integrated Analysis of Agro-ecosystems,*. Boca Raton: CRC Press, 2003.

[77] M. Kaiser and A. Algers, "Food ethics: a Wide Field in Need of Dialogue," *Food Ethics*, vol. 1, no. 1, pp. 1–7, Jun. 2016.

[78] D. Pauly and D. Zeller, "Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining," *Nat. Commun.*, vol. 7, no. 1, p. 10244, Dec. 2016.

[79] AquaBounty Technologies, “Our Salmon.” [Online]. Available: https://aquabounty.com/our-salmon/. [Accessed: 16-Apr-2019].

[80] M. Kaiser, “Practical ethics in search of a toolbox: Ethics of science and technology at the crossroads,” in *Ethics, Law and Society Vol.II*, J. Gunning and S. Holm, Eds. Cardiff: Ashgate Publishing Ltd, 2006, pp. 35–44.

[81] University of Bergen, “The Landscape and Isobars of European Values in Relation to Science and New Technology - Home,” *End results of the project Value Isobars*. [Online]. Available: http://www.value-isobars.eu/. [Accessed: 16-Apr-2019].

[82] S. Bremer, A. S. Haugen, and M. Kaiser, “Whose sustainability counts? Engaging with debates on the sustainability of Bangladeshi shrimp,” in *The ethics of consumption: The citizen, the market and the law.*, H. Röcklin., Wageningen: Wageningen Academic Publishers, 2013.

[83] B. Mepham, “A Framework for the Ethical Analysis of Novel Foods: The Ethical Matrix,” *J. Agric. Environ. Ethics*, vol. 12, no. 2, pp. 165–176, 2000.

[84] M. Kaiser, K. Millar, E. Thorstensen, and S. Tomkins, “Developing the ethical matrix as a decision support framework: GM fish as a case study,” *J. Agric. Environ. Ethics*, vol. 20, no. 1, pp. 65–80, Feb. 2007.

[85] M. Kaiser, “Assessing ethics and animal welfare in animal biotechnology for farm production.,” *Rev. Sci. Tech.*, vol. 24, no. 1, pp. 75–87, Apr. 2005.

[86] T. L. Beauchamp and J. F. Childress, *Principles of biomedical ethics*. Oxford University Press, 2013.

[87] L. Macfarlane, “33 Theses for an Economics Reformation - New thinking for the British economy,” *Open Democracy*, 2017. [Online]. Available: https://neweconomics.opendemocracy.net/33-theses-economics-reformation/. [Accessed: 16-Jul-2019].

[88] E. S. Reinert, *How rich countries got rich and why poor countries stay poor*. Public Affairs, 2008.

[89] C. King, *The British Merchant; or, Commerce Preserv’d, London*. John Darby, 1721.

[90] E. S. Reinert *et al.*, “80 Economic Bestsellers before 1850: A Fresh Look at the History of Economic Thought, Working Papers in Technology Governance and Economic Dynamics no. 74,” 2017.

[91] E. S. Reinert and F. A. Reinert, “33 Economic Bestsellers published before 1750,” *Eur. J. Hist. Econ. Thought*, pp. 1–58, Feb. 2019.

[92] E. S. Reinert and A. M. Daastøl, “The Other Canon: The History of Renaissance Economics, in Globalization, Economic Development and Inequality,” in *Globalization, Economic Development and Inequality*, Edward Elgar Publishing, 2004.

[93] E. S. Reinert, S. Endresen, I. Ianos, and A. Saltelli, “Epilogue: the future of economic development between utopias and dystopias,” in *Handbook of Alternative Theories of Economic Development*, Edward Elgar Publishing, 2016, pp. 738–786.

[94] J. A. Mathews and E. S. Reinert, “Renewables, manufacturing and green growth: Energy strategies based on capturing increasing returns,” *Futures*, vol. 61, pp. 13–22, Sep. 2014.

[95] J. Mayer, *Dark money : the hidden history of the billionaires behind the rise of the radical right*. Anchor, 2017.

[96] F. Falconí, J. Ramos-Martin, and P. Cango, "Caloric unequal exchange in Latin America and the Caribbean," *Ecol. Econ.*, vol. 134, no. April, pp. 140–149, 2017.

[97] E. S. Reinert, "The Terrible Simplifers: Common Origins of Financial Crises and PersistentPoverty in Economic Theory and the new '1848 Moment', DESA working paper Paper No. 8, 8ST/ESA/2009/DWP/88," 2009.

[98] C. Marris, "Final Report of the PABE research project funded by the Commission of European Communities, Contract number: FAIR CT98-3844 (DG 12 - SSMI)," 2001.

[99] K. Russel and D. Hakin, "Broken Promises of Genetically Modified Crops - The New York Times," *The New York Times*, 29-Oct-2016.

[100] G. Gaskell *et al.*, "GM Foods and the Misperception of Risk Perception," *Risk Anal.*, vol. 24, no. 1, pp. 185–194, Feb. 2004.

[101] J. Tait, "More Faust than Frankenstein: the European debate about the precautionary principle and risk regulation for genetically modified crops," *J. Risk Res.*, vol. 4, no. 2, pp. 175–189, Apr. 2001.

[102] M. Kaiser, "Defining the Precautionary Principle; Uncertainties and Values in Science for Policy," in *Contemporary Issues in Medical Ethics, Volume 1, Section for Medical Ethics*, J. H. Solbakk, P. Nortvedt, and A. Nome, Eds. University of Oslo, 2009.

[103] M. Kaiser, J. P. van der Sluijs, S. Beder, V. Hösle, A. Kemelmajer de Calucci, and A. Kinzig, "The Precautionary Principle, A report of an ad hoc working group," 2005.

[104] A. H. Louie, "Robert Rosen's anticipatory systems," *Foresight*, vol. 12, no. 3, pp. 18–29, Jun. 2010.

[105] C. Banks, "Reconstructing Justice in Iraq: Promoting the Rule of Law in a Post-conflict State," *Hague J. Rule Law*, vol. 2, no. 02, pp. 155–170, Sep. 2010.

[106] N. N. Taleb, *Antifragile: Things That Gain from Disorder*. Random House Publishing Group, 2012.

Lens	Role	**Salience** Definition: (or relevance) is intended to reflect the ability of an assessment to address the particular concerns of a user. An assessment is salient to a user if that user is aware of the assessment, and if that user deems that assessment relevant to current policy or behavioural decisions	**Legitimacy** Definition: is a measure of the political acceptability or perceived fairness of an assessment to a user. A legitimate assessment process is one which has been conducted in a manner that allows users to be satisfied that their interests have been taken into account, and that the process has been a fair one	**Credibility** Definition: reflects the scientific and technical believability of the assessment to a defined user of that assessment, often in the scientific community. More credible assessments have done better at ensuring this sort of technical adequacy.
Post-Normal Science	A set of practical insights in science for policy, assisting scientists, stakeholders in working together when facts are uncertain, values in dispute, stakes high and decisions urgent. Quality is assessed with extended peer community, constituted by all those with a stake of interest in the relevant issue	Broad participation through extended peer communities reveals multiple framings and concerns to be included in the integrated assessment	The inclusion of multiple viewpoints (e.g. precautionary concerns) and engagement in extended-peer communities composed by experts, affected or interest citizens, journalists or whistle blowers, ensures more legitimacy compared to a technocratic approach	Credibility is increased by adopting PNS-related knowledge quality assurance tools and processes e.g. NUSAP, checklists
Controversy studies	An approach to analyse openly and systematically, scientific dissent and controversy, in contrast to 'consensus' approaches	Mapping of societal interests and conflicts co-shaping evidence production, use and communication can help in ensuring sound framing of integrated assessments, improving salience	Ensures that multiple sources of evidence and related controversy are included providing a more balanced representation and greater fairness	Credibility is increased as multiple sources of uncertainty and contrasting viewpoints are explicitly dealt with, leading to improved understanding of the quality of narratives
Sensitivity auditing	An approach that addresses models and indicators used at the science-policy interface, which builds on uncertainty and sensitivity analysis, checks against rhetoric use of modelling and deconstructs dubious quantifications	Ensures relevance of the proposed quantification	Allows to deconstruct framings and imaginaries across the board, facilitating a more transparent and open dialogue	The scrutiny of the knowledge base underpinning an integrated assessment through this lens could greatly increase credibility by screening out dubious quantitative outcomes and shoddy methods.

Lens	Role	Salience Definition: (or relevance) is intended to reflect the ability of an assessment to address the particular concerns of a user. An assessment is salient to a user if that user is aware of the assessment, and if that user deems that assessment relevant to current policy or behavioural decisions	Legitimacy Definition: is a measure of the political acceptability or perceived fairness of an assessment to a user. A legitimate assessment process is one which has been conducted in a manner that allows users to be satisfied that their interests have been taken into account, and that the process has been a fair one	Credibility Definition: reflects the scientific and technical believability of the assessment to a defined user of that assessment, often in the scientific community. More credible assessments have done better at ensuring this sort of technical adequacy.
Bioeconomy	A necessary complement to neo-classical economics that analyses the interactions of societal socio-economic processes with ecological processes by focusing on metabolic patterns of socio-ecological systems across different levels and scales	By allowing non-equivalent quantitative representations across levels and scales it allows to identify "winners and losers" hidden in the original story-telling used to support the policy (fight hypocognition)	Allows to deconstruct framings and imaginaries across the options space (feasibility, viability, desirability), facilitating a more transparent and open dialogue	Ensures that the quantification of socio-economic and ecological processes are consistent with feasibility and viability constraints, exposing incompatible assumptions, thus ensuring credibility to the assessment
Ethics of science for governance	Approach tackling the integration of ethical concerns in science development and use at the policy interface. It targets the inclusion of each interest perspective through practical ethics (e.g. value atlas, ethical matrices)	Addresses multiple stakeholders' questions, viewpoints and framings and can contribute in identifying the right questions, thus increasing salience	Stakeholders' perspectives and values are explicitly accounted and discussed, increasing the legitimacy of the outcome	
Non-Ricardian economics	Economic theory that refutes Ricardo's theorem of comparative advantage and discusses implications in the present, neoliberal institutional arrangement, by embracing experience based economic theory - the continental historical schools of economics	It is based on economic theory which has proven relevant and salient through centuries of history of economic thought	It gives voice to other perspectives regarding economic development and power relations, generally not aligned with main international institutions. Likely to improve fairness	Inclusion of alternative framing through which to decompose some axioms regarding economic development

1076