Like blending chalk and cheese – the impact of standard economics in IPCC scenarios

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There is no place where economics and ecosystem science, in particular climate science, are more intimately connected than in the IPCC climate scenarios, their Integrated Assessment Models (IAMs) and the conclusions derived from them. In official parlance, their results should be "policy relevant but not policy prescriptive". Nonetheless past policy discussions have shown that both the climate science part with its scenarios of droughts, floods and storms (e.g., IPCC, 2014a), and the economic part with cost calculations and suggestions for efficient policy strategies (e.g., IPCC, 2014b) have been influential. In the reports, and in particular in IAMs, both are merged, assuming that both disciplines provide adequate descriptions of the parts of reality they are in charge of analysing and understanding. But do they?

1. Background: dealing with complex systems

Since the early 2000s it is a consensus of climate scientists that the climate system is characterised by abrupt change, tipping points, irreversibility and the possibility of multiple stable states: it is a complex, dynamically evolving and highly non-linear, self-organising system:

- Complexity is characterised by time lags (e.g. the ocean delaying terrestrial warming, IPCC, 2013) and positive as well as negative feedback loops. A positive one is less arctic summer ice reducing the albedo and thus increasing warming (Kashiwase et al., 2017). In the same vein, thawing permafrost is releasing methane, a potent greenhouse gas (Knoblauch et al., 2018). A negative one is that increasing CO_2 concentration can stimulate plant growth, enhancing carbon fixation (Culotta, 1995). Some effects are context dependent, like the carbon fixation effect or the global warming contribution of clouds (McCoy et al., 2017).

- The evolution of the system has been felt with the weakening of the polar vortex (the system of circular winds usually keeping polar air in the polar region), resulting in deep-freeze conditions in Canada and the USA (Kretschmer et al., 2018). The weakening of the thermohaline circulation, a hypothetical shock scenario less than a decade ago (Dima and Lohmann, 2010; Spangenberg et al. 2012), is now being observed, and the mechanisms are increasingly better understood (Oltmanns et al., 2018). Another example is the now irreversible retreat of a huge sector of the West Antarctic Ice Sheet (Showstack, 2014; Joughin et al., 2014) – only the speed of melting and with it, the speed of sea level rise is yet unknown.

- The dynamic of the system results from the fact that it is never in equilibrium. Driven by solar radiation, there is no standstill in the climate system; sudden transitions and bifurcations can appear anytime. What is perceived by some observers as an unchanging state and interpreted as equilibrium are instead dissipative patterns (Prigogine and Stengers, 1984; Lockwood, 2001). While such patterns can be relatively stable, they cannot be characterised as unchanging structures but are in fact maintained by a permanent throughput of matter and energy (a candle flame is such a dissipative pattern, and with our body cells replaced in months, years or decades, humans can be described as dissipative pattern as well).

So how do climate scientists deal with the challenge of having to make statements about a system with inherent uncertainty, i.e. a system with an essentially unpredictable behaviour? First of all, they use a wide variety of parameters, software and hardware variations reflecting different approaches and mechanism hypotheses, and diverse data sets. Before coming to a conclusion, the results of these models have to converge, divergence indicating open research questions (Knight et al., 2007). Secondly, climate scientists distinguish the scenarios they are developing from predictions, and thirdly they refrain from quantitative statements when describing the future; they use ordinal scales instead. Fourthly, they qualify their statements by linking each statement (in the summaries for policy makers) with the degree of confidence the scientific community places in it, based on published papers. And finally, they sometimes test “shock” assumptions, i.e. the result of trajectory-changing singular events, to explore the full range of plausible if not necessary probable development options, not least as probabilities cannot be quantified anyway (Spangenberg et al., 2012). Such shocks are hard to model and best represented in the scenario narratives the models should be embedded in (Alcamo, 2001).

This is a high level of caution, reflecting the uncertainties inherent in complex systems, and all the more remarkable as the climate system, despite its size, must be classified as of medium complexity (Allen, 2001; Spangenberg, 2015): after all, the individual parameters and objects (molecules) follow the laws of nature, and only their interplay creates the complexity. Compare this to the models and scenarios developed by biologists and ecologists, where an additional element has to be factored in: unlike molecules, organisms can adapt to a changing environment, in an often unpredictable way. This makes the system even more complex, and modelling it more difficult. It was the recognition of uncertainty and system dynamics by of Holling and May during the 1960s and 1970, which contributed to a stepwise paradigm shift in ecosystem science, away from the stable equilibrium paradigm which had persisted in the earlier decades. That time huge ecosystem models were built and some predictability expected, based on an ontology which perceived the real world as a “stable and infinitely resilient environment where resource flows could be controlled and nature would self-repair into equilibrium” (Folke, 2006, p. 253). The observations and the emphasis on non-linear dynamics, uncertainty, surprise, thresholds and regime shifts starting with Holling (e.g., Holling, 1973) and May (e.g., May, 1976) are today mainstream in the science of ecosystems (Folke, 2006). Consequently, biodiversity scientists are reluctant to make strong statements or predictions and prefer to talk about climate envelopes and how their effects are modified by, amongst others, landscape composition, microclimate, soil conditions and trophic interactions (Dominik et al. 2018), and in particular land use change (Chytrý et al., 2012). Only recently, with evidence for a global decline of insect population manifesting itself (Sánchez-Bayo and Wyckhuys, 2019) and the risks for human food supply resulting from of biodiversity loss now evident (Bélanger and Pilling, 2019), they have become more robust in their statements (IPBES, forthcoming; EEA, forthcoming).

Against this background the question arises what economists can learn from natural sciences regarding the models they use? A society and its economy are systems populated by elements (consumers, firms, etc.) which are neither passively pushed by the laws of nature, nor only reactively adapting to them. Instead they are actively choosing between options including the (often misguided) anticipation of future events. As a result, socio-economic systems represent the highest level of complexity (Allen, 2001; Bossel, 2000). How do economists deal with this complexity of the dynamically evolving, highly non-linear, self-organising system that constitutes our economy? How do they deal with the interaction of the systems, with how and to what degree the economy is changing the ecosystem, and the question to what degree the "age of environmental breakdown" (Laybourn-Langton et al., 2019) is changing the economy, its logic, its functions, structures and prospects? From Adam Smith's "invisible hand" argument to modern general equilibrium theory in the vein of Arrow-Debreu, most of the history of economic thought can be regarded as an attempt to make sense of a complex, non-linear system – the economy. The reminder of this paper is dedicated to show that current mainstream economic thinking is not adequate to deal with this complexity. Section 2 starts with the particularly striking case of economic modelling in the context of Integrated Assessment Models, questioning their capability to accommodate the uncertainty so typical for complex system development. One underlying reason for this weakness is the insufficient reflection on whether to conduct descriptive or normative science, as section 3 shows. That these shortcomings are policy relevant is illustrated in section 4, dealing with the IPCC 1.5°C Report. Section 5 takes a look at the reasons behind, identifying the unreflected approaches to both discounting and economic growth as weak points which must be addressed in any attempt to future-proof economics. Section 6 concludes with an outlook.

2. Precisely incorrect – modelling fiction, not science fiction

Economists combine the science-based climate scenarios (the biodiversity scenarios are rarely taken into account and the issue is dealt with in a more narrative way) with deterministic computable global equilibrium (CGE) models. One reason for doing so is that climate scenarios are most often presenting potential developments up to the midst and the turn of the century, i.e. for the next 30 and 80 years (e.g., IPCC, 2014a; 2018), and deterministic models are the only ones capable of making statements over such a long time period. But are these statements meaningful?

Expect the future as it was

Evolutionary, i.e. non-deterministic econometric models offer rather reproducible results for 15 to 20 years, and as a maximum for 30 years – after that, the results of model runs using the same starting parameters diverge too much for any robust statement to be made (Umweltbundesamt, 2018a; 2018b). The runs of CGE models, due to their deterministic character, are replicable over longer time spans – not all parameters are fully endogenised, and the fundamental structure of the economy they base their calculations on remains unchanged. However, what is the value of forecasts derived from such assumptions? Just imagine the world 80 years ago: World War II had not yet started, fascism reigned not only in Germany but all over Europe, there was an aggressive Japanese empire, Stalin's iron fist in the Soviet Union, the Baltic countries did not exist, Germany was bullying its neighbours, with France and Britain trying to appease it. The world outside America, Europe, China and Japan was mostly colonised. The Great Acceleration of the 1950s/1960s was still far off, the gold standard intact and institutions like the United Nations, the World Bank, IMF, GATT/WTO and international courts did not yet exist. If the world's most sophisticated economists had made a scenario for the next 80 years, up to 2019, it is hardly conceivable that their imagined future would have had any similarities with our present times. The same applies today: economic scenarios for 50, 80 or even more years are pure fiction, not even science fiction. In other words, neoclassical models with their three defining elements of methodological individualism, instrumentalism / utility maximisation intention and market equilibrium are *inherently deterministic* and thus incapable to appropriately reflect the unpredictable dynamics of disequilibrium processes (Arnsperger and Varoufakis, 2006). As deterministic models are representing a zero level of complexity (Allen, 2001), they are bound to fail in the real world (Spangenberg, 2015).

The inherent determinism has further implications: equilibrium models cannot predict tipping points (one reason for their failure in the financial crisis), and they are not capable to deal with uncertainty. Tipping points are non-linearities where small parameter changes can have large impacts on system structure and behaviour, affecting the physical and biological structures as well as kind and cost of the climate policy responses required (Cai et al., 2015). The regime shifts resulting from crossing critical tipping points cannot be modelled by structurally inert models (their differential equations have discontinuities there). Nor can triggering mechanisms be represented as they can be located on different scales of the system and spread to other levels (Rocha et al., 2018), a mechanism not foreseen in CGE models.

Uncertainty and ignorance

The real-world policy relevance of economic modelling is also undermined by the fact that strategic decisions are often confronted with risk, uncertainty and ignorance (Mayumi and Giampietro, 2001; van der Sluijs, 2012). In non-deterministic systems

- **risk** means knowing the potential impacts of a decision, and the probability that they occur,
- **uncertainty** means knowing the potential impacts, but having no idea about the probability they might occur, and
- **ignorance** means having no idea of either the potential impacts nor their probability.

These distinctions are important as the policy suggestions derived from the models are to be applied in a world characterised by the lack of full knowledge and a high level of uncertainty (Prigogine 1997), and the different levels of knowledge deficits call for different kinds of responses, as summarised in table 1.

Table 1 Knowledge and decision making

Situation	**Kind of system**	**State of knowledge**	**Futures**	**Action required**
Certainty	Deterministic	"known" future system behaviour, probability =1	Prediction	Adaptation, preparation for the events to come
Risk	Dynamic	"known" impacts, "known" probabilities	Stochastic prediction	Preparing for adaptation, prevention to reduce known pressures, directly or by modifying their driving forces
Uncertainty	Self-organising and evolving systems	"known" impacts with "unknown" probabilities	Scenarios, vulnerability analysis	Precautionary prevention to reduce potential pressures
Ignorance	Self-organising, evolving and, undetermined systems	"unknown" impacts, "unknown" probabilities, e.g. surprises, shocks or "wild cards"	Scenario story lines, fiction	Precaution, action taken to anticipate, identify and reduce the impact of "surprises"

Source: EEA (2004), extended and modified

That their deterministic models cannot deal with real-world uncertainty, and that this hampers the relevance of their models, is not unknown to standard economists (e.g. Lange and Treich, 2008) – as a response, some have developed various classes of “fuzzy system models” (Lontzek et al., 2012), amongst them the dynamically stochastic general equilibrium models DSGEs (Syll, 2010). According to Yager and Filev (1994, p. xiii), the concept of fuzziness can directly attributed to L.A. Zadeh who intended to provide a tool to help in the modelling of complex phenomena, especially, but not restricted to those involving human agents. They claim that “By permitting a certain amount of imprecision in our models, we provide a robustness that allows us to model complex situations, which we might not otherwise be able to model and also provide a means for including the inherent vagueness of the human process of conceptualizing the external world”, but that depends on how the “imprecision” is realised in what they call mathematical models. Usually cardinal parameters are replaced by probability distributions, forming a stochastic “cloud” around the initial parameter value. However, such “imprecisions” are not providing the “robustness that allows us to model complex situations” as Yager and Filev had hoped insofar as if they are stochastic probability distributions, they represent quantifiable risks (the everyday business of insurance companies), but not uncertainty, let alone ignorance. The results are predictable, and their probability is known – the models, including the DSGEs, are still deterministic, and due to the equilibrium assumptions ruling out system structure development, processes and developments are even assumed to be reversible.

Digging deeper

To understand why mainstream economics today is grappling to deal with complex systems and structural uncertainty, a brief look at the history of economic thought is helpful. In the more distant past, at least some economic scholars have incorporated structural uncertainty into their theories. Whereas in the writings of economists such as Mill, Keynes and even Hayek structural uncertainty played a certain role in explaining macro-structures of the economy, today the rational actor model has led to a reductionist containment of complexity as well as structural uncertainty. In the aftermath of the marginalist revolution and with its roots in Benthamian utilitarianism, the economic mainstream began to shift its attention away from understanding the causes of wealth, the functioning of markets and the macro-structure of the economy in order to focus on individual behaviour and choice as core units of analysis (Herfeld, 2013). Macroeconomic theorising is required to provide a microeconomic justification – exactly the opposite order of what it should be, taking into account the emerging properties on higher system levels.

However, the real birth of economics as a science of choice happened right after WWII with a more axiomatic formulation of rationality (Herfeld, 2013). This concept, which was initially put forward by von Neumann and Morgenstern, would set the standard for the treatment of the notion of uncertainty in post-WWII mainstream economics (Muthoo, 1999). They proposed conditions under which the maximisation of expected utility holds, which can be arrived at in case of given objective probabilities attached to the utilities that might be realised in a choice situation. Thus, it is a theory of risk and does not apply to situations where probabilities are not known (Gilboa, 2009). It was Savage (1954), who would suggested an approach how to realise expected utility maximisation in situations of structural uncertainty where no objective probabilities are known. Building on the concept of subjective probabilities and combining it with the idea of expected utility proposed by von Neumann and Morgenstern, Savage’s theorem claims that decisions under uncertainty can in fact be converted into decisions under risk. According to Savage, the only difference is that it is not objective probabilities but merely subjective probabilities and thus beliefs of the decision maker herself, which are incorporated into the model. However, he warned that his theory of subjective probabilities "should only be applied in small worlds in which it is possible to 'look before you leap'" (Millner et al., 2013, p. 22). Nonetheless economists considered it possible to transform choices under structural uncertainty into choices under risk using Savage's theorem and applying it far beyond its domain of applicability. This way the expected utility framework combined with the assumption of rational agents and market equilibria led to complicated but not complex, rather neat and tidy economic models spanning over longer periods of time – precisely those deterministic CGE/DSGE models which are today combined with science-based climate scenarios. In a nutshell, currently economists apply their highly sophisticated tools to areas where they cannot provide meaningful results: the domain of legitimate applicability might be short term assessments, for time spans short enough to make the assumption plausible that major system changes have not occurred during the time period covered by an analysis. A future-proof economic theory will address these shortcomings the same way other sciences have done so, even it requires giving up highly valued tools and methods.

In the meantime, there is another problem associated with the reductionist approach of modern economics towards complex systems and to deriving recommendations regarding their management.

3. A fine line – descriptive or normative science?

Next to the inability to describe long-term developments and to take into account the structural uncertainty of complex systems, there is a more fundamental problem regarding current economic modelling manifesting itself in IAM/DSGE models. It consists of the fact that economic models are presented as being purely descriptive, while they actually carry quite some normative baggage. This becomes particularly relevant as the function of economics in society changed from depicting and explaining the reality of the economic system to serving as a tool to facilitate political decision making processes.

Through the rise of the rational choice paradigm and economics' development into a science of choice, it has become vague whether its approach to decisions is more of a descriptive or of a normative character. Usually, in neoclassical economics, expected utility theory is claimed to be used as a purely descriptive theory. Yet this claim is false as the idea of rational choice in conjunction with utilitarian assumptions is inherently tied to a specific concept of welfare and its normative assumptions (Muthoo, 1999). These circumstances have made it almost impossible for economists to draw a precise line between a descriptive and a normative approach, although few are aware of this challenge. This is dangerous as it disguises the outcomes of economic models as purely rational, whereas in fact they contain a plethora of underlying normative assumptions representing a specific world view (Spangenberg, 2016).

This has some very real and direct consequences when it comes to climate scenarios and the corresponding IAM/DSGE models: they are built in order to find solutions on how to achieve certain emission reduction targets (Kuhnhenn, 2018). The underlying economic models are optimisation models, which – under given boundary conditions – try to maximise the social utility function, most often represented by the GDP. Thus, in IAM/DSGE models, what is presented as the "optimal" outcome is more wealth in a national economy, in monetary terms (distribution plays no role). In such models, any measures leading to a reduction of GDP growth would not be regarded as an "optimum" as they would be regarded as "expensive" in and by the model. The consequence is that measures, which might lead to less production and consumption either cannot be depicted or are not used (Kuhnhenn, 2018). This is striking as changes of the consumption patterns and levels are a necessary condition for reaching the climate goals, as described above. In summary, it is our very standards of evaluation, which lead to deeply ideologically biased policy recommendations being presented as "objective" scientific insights, which has made economics the favourite legitimation science of neoliberal decision makers in politics and business.

4. The 1.5°C calamity

Until 2015 the most frequently cited and politically endorsed goal of climate policy was limiting global warming to 2°C. At the Paris Climate Conference, however, Small Island States and civil society lobbying brought about an unexpected change: the UNFCCC Conference of Parties agreed that the goal should be tightened to a warming level significantly below 2°C and at best not surpassing 1.5°C. Climate science was taken by surprise, but by taking a closer look at the discrepancy of impacts between 1.5° and 2°C came to conclusions strongly supportive to the 1.5°C maximum. Hansen et al. (2016) showed that evidence from paleoclimate data, climate modelling, and observations supported the assumption that 2 °C global warming could be dangerous for ice melt, sea level rise and superstorms. Two years later the IPCC confirmed the warning and pointed to a rapidly worsening situation when the temperature increase surpasses 1.5°C and reaches 2°C (IPCC, 2018). Climate science called for "rapid, far-reaching and unprecedented changes in all aspects of society" and highlighted the need for stringent policy reaction to avoid the potentially catastrophic effects which can occur when the 1.5°C threshold is surpassed, in particular as a result of the highly non-linear character of the climate system.

New targets require new policy strategies, and new economic assessments. The IPCC (2018) presents four scenarios, three the "usual suspects" (variants of the SRES scenarios used by the IPCC since 2002) and one explicitly ambitious sustainability scenario, including all kinds of technologies and policy interventions to reduce greenhouse gas emissions. The potential of these technologies is assessed by analysing the technical and biophysical limits and the cost of each measure (Smith et al., 2016). So do the scenarios foresee a stop the increase of greenhouse gas concentrations in the Earth's atmosphere sufficiently and in due time? Unfortunately not – all four socio-economic scenarios and storylines linking the physical scenarios to the socio-economic domain expect an overshoot of greenhouse gases and thus temperatures. These are intended to be temporary (the scenarios vary in the level and duration of overshoot).

However, in dynamically evolving, self-organising systems such as the environment and the society and its economy, systems changes emerging during the overshoot period are irreversible and initiate path dependent developments: you never cross the same river twice, and you never visit the same town twice. Thus it is obvious that an overshoot – temporary or permanent – is not acceptable once the lessons from complex systems theory are taken into account. Compensation later, in the second half of this century, by "negative emissions",[143] i.e. technologies extracting more CO_2 from the atmosphere than is still being emitted in the

[143] The charm of this definition is that one only has to "think big" regarding the technologies to avoid a comprehensive phase out of fossil fuels.

same time period offers no guaranty that it will not trigger changes beyond those accepted by setting the threshold.

Physics doesn't negotiate, so the task of economic and policy scenarios is to find ways how the limits identified can be kept, and this is where the IPCC report fails: in the suggestions how to do its own bidding. The technologies suggested in the scenarios to make good for a more or less large overshoot (without being able to quantify what this implies for avoiding tipping points) by providing "negative emissions" in the second half of the century include readily available and so far more experimental approaches; upscaling would be needed in most cases:

- One short-term available option is large-scale pyrolysis of organic matter, using the resulting carbon as soil stabiliser (known from the Amazon basin as "Terra Preta"). While it could indeed sequester significant amounts of carbon and reduce soil nitrous oxide emissions (Cayuela et al., 2014), there is a high probability that with it, aromatic and in particular polycyclic aromatic compounds (potentially toxic, carcinogenic and mutagenic) plus heavy metals would be inserted into the soil and accumulate there.

- The preferred longer-term option is Bio-Energy with Carbon Capture and Storage (BECCS), large-scale biomass cultivation as energy source, with subsequent carbon capture and underground storage. It is a combination of existing but separate technologies requiring integration, upscaling and commercialisation before effects can be expected. Both elements of that "rescue concept" have been criticised – a sustainable biomass base has limitations regarding energy provision (in particular in competition for land against food production), and large scale plantations would be damaging biodiversity (EEA, 2006; Spangenberg et al., 2014; Smith et al., 2016)., CCS has been questioned regarding its safety (storing carbon dioxide for centuries and longer), and the enormous energy consumption it entails (Stephens, 2013). Even the criticism articulated from an ecological and nature protection point of view in the last IPCC report has been ignored or at least side-lined (IPCC, 2014a), as has been the critical assessment by the Global Assessment of the Intergovernmental Platform on Biodiversity and Ecosystem Services, the biodiversity pendant of the climate-focussed IPCC (IPBES, forthcoming). Furthermore, the European Academies' Science Advisory Council recently concluded that "bioenergy with carbon capture and storage (BECCS) remains associated with substantial risks and uncertainties, both over its environmental impact and ability to achieve net removal of CO_2 from the atmosphere." (EASAC, 2019) Nevertheless, according to IPCC economists, "there is no alternative".

Essentially, the strategy recommended by the IPCC is one of shifting problems into the future, following the old and discredited motto "grow now, clean up later". The belief in technological solutions is a narrow and inadequate approach to changing the environmental performance of the economy, but – unfortunately – not unusual amongst standard economists. In essence it implies kicking the can down the road (or even in the long grass), by shifting the risk of failure to future generations. Believing in the possibility to revert the impacts of threshold transgressions by compensation measures later on is a clear indication that the authors have not understood the very character and the dynamics of complex evolving systems – or at least they base their suggestions on models which are unable to adequately deal with the complexity of the systems they are supposed to represent.

The technology fix corresponds with the supply-side policy focus dominating current economic theory and policy, leading to the neglect of demand side management. Demand editing and nudging are even denounced as paternalising, and rejected – but they are no more paternalising than the ban on toxics to be sold in the supermarket. Recent studies have shown that adding consumption sufficiency to production efficiency makes it significantly easier to reach the Paris targets (Mundaca et al., 2019; Wachsmuth and Duscha, 2019) and overcome rebound effects: sufficiency is necessary to make efficiency effective.

In a nutshell: the world views and established habits of standard economics misguide the policy recommendations derived, increase the risks through accepting a (temporary) overshoot, ignore irreversible changes happening in the meantime and rely on technology fixes to provide for “negative emissions” which are either proven to be environmental disasters (large-scale pyrolysis) or untested, coming too late and if coming, a threat to the web of life (BECCS). They rest on an overly optimistic belief in technology and ignore policy options not in line with their supply-side focussed economic ideology.

5. Money makes the world go down?

Economics in itself has been evolving since its inception, and the understanding of central terms like “value” has consistently changed over time (Baldissone, 2008). In this section we address two key traits of current economic thinking, the way the future is valued and the role of economic growth.

The discounting procedure

Whether from an economic point of view policy measures should be taken now or later depends on how the costs are calculated – this is supposed to be the core competence domain of economists. Some problems like how to calculate the value of a human life are unsolvable questions where insurance mathematics, human rights and value theories collide, but others could be solved if only economic orthodoxy would give way to more empirically based procedures. Much of the economic dispute is about the appropriate discount rate, about the implicit choice of the value allocated to the future. Besides the belief in problem-solving technologies and the reliance on ever-lasting economic growth (higher affluence in the future would diminish the relative importance of cost shifted to future generations), the key argument is that future consumption should be discounted simply because it takes place in the future and people generally prefer the present to the future (inherent discounting).

This is problematic in many ways. In particular, discounting the value of future consumption, gains and liabilities makes a very strong normative statement concerning the value of future generations and the freedom of choice left to them. A high discount rate decreases the estimated benefit of actions taken today designed to reduce greenhouse gas emissions (Moxnes, 2014), and makes it appear plausible to “kick the can down the road”. For instance, Nicholas Stern chose a low average discount rate (he applied a stochastic approach whereby the discount rate varied with the expected outcomes) for his famous Stern Review and was criticised for this by William Nordhaus (who 2018 received the Bank of Sweden price commemorating Alfred Nobel for his work on the economics of global warming). Nordhaus criticised the Review for its use of a low discount rate and argued for taking today’s marketplace real interest rates[144] (Stern, 2006; Nordhaus, 2007). On the opposite side,

[144] Times are changing: with market interest rate close to zero since a decade, Nordhaus’ line of argumentation would now imply much more drastic measures to be taken than in Stern’s initial approach.

ecological economists like Clive Spash criticised the study for its use of cost benefit analysis including discounting the future and Ted Trainer for the narrowness of its economic perspective (Spash, 2007; Trainer, 2008). The market interest rate approach by Nordhaus also suffers from the fact that while indeed humans often prefer the present to the future, not all do that, all do it differently and not all objects are treated the same. For instance, Gowdy et al. (2013) find that in many cases discounting makes no sense at all; in these cases policies could instead be ranked by inspecting policy consequences over time (Moxnes, 2014). Even where discounting is applicable, hyperbolic discounting is better reflecting human preferences than exponential discounting (Gowdy et al., 2013); it can be introduced into classical welfare functions as Gollier (2011) has shown. However, guided by their methodological assumptions, neoclassical economists rarely ask if the concept of exponential discounting is appropriate at all, if discounting as such makes sense, but if anything, they discuss the discount rate, i.e. the exponent in function defined as exponential curve.

So do the IPCC economists, and by assuming a discount rate of 4% they follow the Nordhaus pledge for higher discount rates, and thus a lower profitability of climate mitigation policies. Hyperbolic accounting, which would lower the profitability threshold for climate policy measures is not discussed at all, nor are far-reaching demand side policies for energy reduction (the sustainability scenario at least touches upon the issue in passing).

The growth obsession

Assuming higher affluence in the future is one of the justifications for discounting; it appears to be an assumption which cannot be questioned, a holy grail of standard economics. Together with the neglect of demand side policies this may be the reason why all four IPCC scenarios assume continuous economic growth, and transgress the 1.5°C threshold – which makes them dependent on the use of "negative emission" technologies. The scenarios assume economic growth rates between 0.6% and 1.7% for the affluent countries, and 1.1% to 2.8% for the global economy (Kuhnhenn, 2018). The assumption is that growth is exponential, implying an accelerating growth in absolute terms – in contradiction to empirical analyses which found that the vast majority of mature economies follows a linear, rather than an exponential growth path (Lange et al., 2018).

The IPCC offers no scenario exploring the effects of discontinuing economic growth, at least in the affluent countries, any time between now and 2100. Considering options like a policy of degrowth was rejected by IPCC economists as the results of such assumptions would be economically implausible. Thus assumptions of 80 years of growth and the risk of hothouse climate conditions are considered a realistic option, while the deep structural change necessary to limit climate damage isn't – at least not if it ends permanent economic growth.

However, since the 1972 publication of the "Limits to Growth" report to the Club of Rome it is well known that economic growth and resource consumption are closely linked, and that efficiency gains minus rebound effects can ease the burden, they do not eliminate the links (Meadows et al., 1972). Long-term decoupling of the overall physical throughput of an economy from its monetary growth has not been achieved anywhere, and given the limits of possible efficiency increases resulting from physics, technology and cost it is also implausible. Most economists agree these days that growth cannot be eternal, that there will be limitations, but consider them to be far away. They tend to ignore the rising trend of the Energy Return On (Energy) Investment EROI, i.e. the fact that the low hanging fruits in terms of energy sources and deposits of minerals and ores have been exploited, and that new resources tend to require more input for the same output, reducing the net production (Sers and Victor, 2018). This and other factors contributing to a secular stagnation of economic growth (Schmelzer, 2015) have been the arguments which led even some business-affiliated research institutes in Germany to support a "precaution-oriented post-growth position" (IÖW et al., 2018).

Sustainable development in the affluent countries, starting with a phase of degrowth (Victor, 2012; Eversberg and Schmelzer, 2018) and turning into a steady-state economy once the necessary reductions of resource consumption have been achieved (Daly, 1973) could contribute significantly to avoid a climate overshoot. Thus it is high time that the economic profession leaves the world of sterile models behind, which are incapable of capturing the dynamics of living and social systems, and takes a scientific turn towards fact-based argumentation and the search for evidence. The CGE/DSGE models are castles in the clouds, and the conclusions drawn from them are dangerous for humankind and the global environment.

6. Outlook

The discipline of economics has played and continues to play a major role in leading humankind towards the ultimate calamity. It is driven by world views and their ontologies, which are more based on Newton's mechanics than rooted in modern science's understanding of systems complexity (Spangenberg, 2016). To make good for its past harmful role, and to provide guidance for economic and other policies for a sustainable 21st century, economics must change. Change would have to be deep and broad; for instance, economics would have to change its ontology (the economy is a subsystem of society which in turn is embedded in the environmental systems), its epistemology (not least to accommodate ignorance and uncertainty), its anthropology (accepting human beings in their ambivalence instead working with the *homo oeconomicus* abstraction and its derivates) and its axiology (accepting diverse value systems to replace "economic rationality").

Part of adapting its ontology to modern scientific standards would be to overcome the mechanistic world view and replace it by one based on a physical economy of matter and energy flows, and abolish equilibrium thinking and modelling to replace it by evolutionary approaches (Spangenberg, 2018). This would help avoiding what Herman Daly (2000) has called "dumb mistakes", like for instance considering the collapse of agriculture (Bélanger and Pilling, 2019) as a minor problem, as agriculture only makes up for 2 to 4% of the GDP in affluent countries, without asking about what people will eat in that case. It would also offer the opportunity to better understand the physical processes of the environment impacting on the economy, for instance the role of tipping points and their relevance for cost-impact analyses of climate policies (Cai et al., 2015). In short, economics has to be reinvented if it is to become a force for leading us away from catastrophe – rather than toward it. Taking the science of complexity on board would be a first step in this direction.

Is this an illusory demand? Being a neoclassical economist has been the career and income base for scholars, consultants, administrators and politicians – they would hardly declare "*mea culpa, mea maxima culpa*" and leave their positions (they could hardly stay after their lack of real-world qualifications has been revealed). But this should happen as soon as possible, as even with environmental and climate evidence mounting, adaptation and precaution remain limited and restricted by the existing system logics and institutionally based motivational and incentive structures, rather than by externally defined "rational" motivations (Andersson and Keskitalo, 2018). Several schools of heterodox thought have developed the means for economic research and advice generation, like stock-flow consistent input–output models (Berg et al., 2015), system dynamics models like WORLD6, simulating potential future supply and supply deficiencies of a number of natural resources (Umweltbundesamt, 2018a), evolutionary models like the fully endogenised GINFORS (Umweltbundesamt, 2018b; Spangenberg et al., 2012) or cybernetic models based on orientation strategy simulating sustainable system behaviour in changing environments (Bossel, 2000).

So while there is an abundance of ideas and tools, it is still plausible to expect a continued dominance of neoclassical power holders, and an Economics 6.0 (if you count Physiocrats, classics, marginalists, Keynesians and neoclassicals as earlier incarnations of economics) will only become hegemonial once the representatives of the existing hegemony have disappeared, or standard economics has fallen into so complete disregard by decision makers that standard economists give up and leave the sinking ship. So far however, such a turn of the tide is not in sight as even without good prognoses, scenarios and policy recommendations for sustainability, standard economics has an important function in legitimising neoliberal policies.

References

Alcamo, J. (2001) "Scenarios as tools for international environmental assessments." EEA European Environment Agency Expert Corner Report "Prospects and Scenarios" No. 5. Luxembourg, Office for the Official Publications of the European Communities.

Allen, P. M. (2001) "The Dynamics of Knowledge and Ignorance: Learning the New Systems Science." In *Integrative Systems Approaches to Natural and Social Dynamics*. H. M. Matthies, J. Kriz. Berlin: Heidelberg / New York: Springer, pp 3-30.

Andersson, E., Keskitalo, E. C. H. (2018) "Adaptation to climate change? Why business-as-usual remains the logical choice in Swedish forestry." *Global Environmental Change*, 48, pp. 76-85.

Arnsperger, C., Varoufakis, Yanis (2006) "What is neoclassical economics?" *post-autistic economics review*, 38, pp. 2-12.

Baldissone, R. (2008) "Beyond economic fundamentalism." *real-world economics review*, 45, pp. 33-53.

Bélanger, J., Pilling, D. (eds.) (2019) "The State of the World's Biodiversity for Food and Agriculture." Assessments. FAO Food and Agriculture Organization of the United Nations, Commission on Genetic Resources for Food and Agriculture. Rome: FAO.

Berg, M., Hartley, B., Richters, O. (2015) "A stock-flow consistent input–output model with applications to energy price shocks, interest rates, and heat emissions." *New Journal of Physics,* 17(1), p. 015011.

Bossel, H. (2000) "Policy assessment and simulation of actor orientation for sustainable development." *Ecological Economics*, 35(3), pp. 337-355.

Cai, Y., Judd, K. L., Lenton, T. M., Lontzek, T. S., Narita, D. (2015) "Environmental tipping points significantly affect the cost−benefit assessment of climate policies." *Proceedings of the National Academy of Sciences*, 112(15), pp. 4606-4611.

Cayuela, M. L., van Zwieten, L., Singh, B. P., Jefferey, S., Sánchez-Monedero, A. M. (2014) "Biochar's role in mitigating soil nitrous emissions: A review and meta-analysis." *Agriculture Ecosystems Environment,* 191, pp. 5-16.

Chytrý, M., Wild, J., Pyšek, P., Jarošík, V., Dendoncker, N., Reginster, I., Pino, J., Maskell, L. C., Vilà, M., Kühn, I., Spangenberg, J. H., Settele, J. (2012) "Projecting trends in plant invasions in Europe under different scenarios of future land-use change." *Global Ecology and Biogeography*, 21(1), pp. 75-87.

Culotta, E. (1995) "Will plants profit from high CO_2?" *Science*, 268(5211), p. 654.

Daly, H. E. (2000) "When smart people make dumb mistakes." *Ecological Economics,* 34(1), pp. 1-3.

Daly, H. E. (1973) *Toward a Steady-State Economy*. San Francisco: W.H. Freeman.

Dima, M., Lohmann, G. (2010) "Evidence for two distinct modes of large-scale ocean circulation changes over the last century." *Journal of Climate*, 23(1), pp. 5-16.

Dominik, C., Seppelt, R., Horgan, F. G., Settele, J., Václavík, T. (2018) "Landscape composition, configuration, and trophic interactions shape arthropod communities in rice agroecosystems." *Journal of Applied Ecology*, 55(5), pp. 2461-2472.

EASAC European Academies' Science Advisory Council (2019) *Forest bioenergy, carbon capture and storage, and carbon dioxide removal: an update*. EASAC. Halle (Saale), Germany / Brussels, Belgium.

EEA European Environment Agency (2004)" A Framework for Evaluating Complex Scientific Evidence on Environment Factors in Disease Causation." Background Paper No. 3 from the European Environment Agency for the EU Environment and Health Strategy. EEA, Copenhagen.

EEA European Environment Agency (2006) "How much bioenergy can Europe produce without harming the environment?" EEA Report 7/2006. EEA. Copenhagen.

EEA European Environment Agency (forthcoming) "State of the Environment Report - SOER 2020" Integrated Assessment report. EEA. Copenhagen.

Eversberg, D., Schmelzer, M. (2018) "The degrowth spectrum: convergence and divergence within a diverse and conflictual alliance." *Environmental Values,* 27(3), pp. 245-267.

Folke, C. (2006) "Resilience: The emergence of a perspective for social–ecological systems analyses." *Global Environmental Change*, pp. 253–267.

Gilboa, I. (2009) *Theory of Decision under Uncertainty*. Cambridge.

Gollier, C. (2011) "Discounting and risk adjusting non-marginal investment projects." *European Review of Agricultural Economics,* 38(3), pp. 325-334.

Gowdy, J., Rosser Jr, J. B.Roy, L. (2013) "The evolution of hyperbolic discounting: Implications for truly social valuation of the future." *Journal of Economic Behavior & Organization*, 90, Supplement, pp. S94-S104.

Hansen, J., Sato, M., Hearty, P., Ruedy, R., Kelley, M., Masson-Delmotte, V., Russell, G., Tselioudis, G., Cao, J., Rignot, E., Velicogna, I., Kandiano, E., von Schuckmann, K., Kharecha, P., Legrande, A.N., Bauer, M., Lo, K.W. (2016) "Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2 °C global warming could be dangerous." *Atmospheric Chemistry and Physics* Discussion, (16), pp. 3761-3812.

Herfeld, C. (2013) "PhD thesis summary: The many faces of rational choice theory." *Erasmus Journal for Philosophy and Economics*, pp. 117-121.

Holling, C. S. (1973). "Resilience and stability of ecological systems." *Annual Review of Ecology and Systematics,* (4), pp. 1-23.IÖW Institut für ökologische Wirtschaftsforschung, RWI – Leibniz-Institut für Wirtschaftsforschung, Wuppertal Institut für Klima Umwelt Energie (2018). Gesellschaftliches Wohlergehen innerhalb planetarer Grenzen. Der Ansatz einer vorsorgeorientierten Postwachstumsposition. UBA Texte 89/2018. Umweltbundesamt. Berlin, Germany.

IPBES Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (forthcoming). *The Global Assessment.* IPBES, Bonn, Germany.

IPCC Intergovernmental Panel on Climate Change (2013) *Climate Change 2013: The Physical Science Basis*. Cambridge, New York: Cambridge University Press.

IPCC Intergovernmental Panel on Climate Change (2014a) *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. New York, Nairobi, IMO, UNEP.

IPCC Intergovernmental Panel on Climate Change (2014b) *Climate Change 2014: Mitigation of Climate Change*. New York: Cambridge University Press.

IPCC Intergovernmental Panel on Climate Change (2018) "Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty." *IPCC Special Report 15*. Geneva, Switzerland, World Meteorological Organization.

Lange, A., Treich, N. (2008) "Uncertainty, learning and ambiguity in economic models on climate policy: some classical results and new directions." *Climatic Change,* 89(1-2), pp. 7-21.

Laybourn-Langton, L., Rankin, L., Baxter, D. (2019) *This is a crisis. Facing up to the age of environmental breakdown*. IPPR Institute for Public Policy Research, London

Joughin, I., Smith, B. E., Medley, B. (2014) "Marine ice sheet collapse potentially under way for the Thwaites Glacier Basin, West Antarctica." *Science*, 344(6185), pp. 735-738.

Kashiwase, H., Ohshima, K. I., Nihashi, S., Eicken, H. (2017) "Evidence for ice-ocean albedo feedback in the Arctic Ocean shifting to a seasonal ice zone." *Scientific Reports,* 7(1), p. 8170.

Knight, C. G., Knight, S. H. E., Massey, N., Aina, T., Christensen, C., Frame, D. J., Kettleborough, J. A., Martin, A., Pascoe, S., Sanderson, B., Stainforth, D. A., Allen, M. R. (2007) "Association of parameter, software and hardware variation with large scale behavior across 57,000 climate models." *Proceedings of the National Academy of Sciences of the USA,* 104(30), pp. 12259-12264.

Knoblauch, C., Beer, C., Liebner, S., Grigoriev, M. N.Pfeiffer, E.-M. (2018) "Methane production as key to the greenhouse gas budget of thawing permafrost." *Nature Climate Change*, 8(4), pp. 309-312.

Kretschmer, M., Coumou, D., Agel, L., Barlow, M., Tziperman, E., Cohen, J. (2018) "More-persistent weak stratospheric polar vortex states linked to cold extremes." *Bulletin of the American Meteorological Society,* 99(1), pp. 49-60.

Kuhnhenn, K. (2018) *Wachstum in der Klimawissenschaft: Ein blinder Fleck. Globale Szenarien aus wachstumskritischer Perspektive*. Heinrich-Böll-Stiftung, Berlin, Germany.

Lange, S., Pütz, P., Kopp, T. (2018) "Do mature economies grow exponentially?" *Ecological Economics,* 147, pp. 123-133.

Lockwood, J. G. (2001) "Abrupt and sudden climatic transitions and fluctuations: A review." *Journal of Climatology*, 21(9), pp. 1153-1179.

Lontzek, T. S., Cai, Y., Judd, K. L. (2012) "Tipping points in a dynamic stochastic IAM, RDCEP. " Working Paper 12-03. The Center for Robust Decision Making on Climate and Energy Policy. Chicago, IL, USA.

Mayumi, K., Giampietro, M. (2001) "The epistemological challenge of modelling sustainability: risk, uncertainty and ignorance." Paper presented at the European Society for Ecological Economics' Frontiers I conference, Cambridge University, UK, 4-7 July 2001.

van der Sluijs, J. P. (2012) "Uncertainty and dissent in climate risk assessment: a post-normal perspective." *Nature and Culture,* 7(2), pp. 174-195.

May, R. M., (ed.) (1976) *Theoretical Ecology - Principles and Applications*. Blackwell Scientific Publications, Oxford, UK.

Mayumi, K., Giampietro, M. (2001) "The epistemological challenge of modelling sustainability: risk, uncertainty and ignorance." Paper presented at the European Society for Ecological Economics' Frontiers I conference, Cambridge University, UK, 4-7 July 2001.

McCoy, D. T., Eastman, R., Hartmann, D. L., Wood, R. (2017) "The Change in Low Cloud Cover in a Warmed Climate Inferred from AIRS, MODIS, and ERA-Interim." *Journal of Climate*, 30(10), pp. 3609-3620.

Meadows, D. H., Meadows, D. L., Randers, J., Behrens, W. W. (1972) *Limits to Growth. A Report to the Club of Rome*. New York: Universe Books.

Millner, A., Dietz, S., Heal, G. (2013) "Scientific ambiguity and Climate Policy." *Environmental Resource Economics*, pp. 21-46.

Moxnes, E. (2014) "Discounting, climate and sustainability." *Ecological Economics*, 102, pp.158-166.

Mundaca, L., Ürge-Vorsatz, D., Wilson, C. (2019) "Demand-side approaches for limiting global warming to 1.5°C." *Energy Efficiency,* 12(2), pp. 343-362.

Muthoo, A. (1999) "Rationality in the Face of Uncertainty." In *The Elgar Companion to Consumer Research and Economic Psychology*, pp. 487-495. Cheltenham.

Nordhaus, W. D. (2007) "A review of the stern review on the economics of climate." *Journal of Economic Literature*, 45(3), pp. 686–702.

Oltmanns, M., Karstensen, J., Fischer, J. (2018) "Increased risk of a shutdown of ocean convection posed by warm North Atlantic summers." *Nature Climate Change*, 8(4), pp. 300-304.

Prigogine, I. (1997) *The end of certainty: Time, Chaos and the new Laws of Nature*. New York: The Free Press.

Prigogine, I., Stengers, Isabelle (1984) *Order out of Chaos: Man's New Dialogue with Nature*. London: Heinemann.

Rocha, J. C., Peterson, G., Bodin, Ö., Levin, S. (2018) "Cascading regime shifts within and across scales." *Science*, 362(6421), pp. 1379-1383.

Sánchez-Bayo, F., Wyckhuys, K. A. G. (2019) "Worldwide decline of the entomofauna: A review of its drivers." *Biological Conservation,* 232, pp. 8-27.

Savage, L.J. (1954) *The Foundations of Statistics*. New York: John Wiley.

Schmelzer, M. (2015) "The growth paradigm: History, hegemony, and the contested making of economic growthmanship." *Ecological Economics,* 118, pp. 262-271.

Sers, M. R., Victor, P. A. (2018) "The energy-emissions trap." *Ecological Economics*, 151, pp. 10-21.

Showstack, R. (2014) "Sector of West Antarctic Ice Sheet in 'irreversible retreat'." *Eos, Transactions American Geophysical Union*, 95(20), pp. 168-168.

Smith, P., Davis, S. J., Creutzig, F., Fuss, S., Minx, J., Gabrielle, B., Kato, E., Jackson, R. B., Cowie, A., Kriegler, E., van Vuuren, D. P., Rogelj, J., Ciais, P., Milne, J., Canadell, J. G., McCollum, D., Peters, G., Andrew, R., Krey, V., Shrestha, G., Friedlingstein, P., Gasser, T., Grubler, A., Heidug, W. K., Jonas, M., Jones, C. D., Kraxner, F., Littleton, E., Lowe, J., Moreira, J. R., Nakicenovic, N., Obersteiner, M., Patwardhan, A., Rogner, M., Rubin, E., Sharifi, A., Torvanger, A., Yamagata, Y., Edmonds, J., Yongsung, C. (2016) "Biophysical and economic limits to negative CO_2 emissions." *Nature Climate Change*, 6(1), pp. 42-50.

Spangenberg, J. H., Bondeau, A., Carter, T. R., Fronzek, S., Jaeger, J., Jylhä, K., Kühn, I., Omann, I., Paul, A., Reginster, I., Rounsevell, M., Schweiger, O., Stocker, A., Sykes, M. T., Settele, J. (2012) "Scenarios for investigating risks to biodiversity." *Global Ecology and Biogeography*, 21(1), pp. 5-18.

Spangenberg, J. H., von Haaren, C., Settele, J. (2014) "The Ecosystem Service Cascade: further developing the metaphor. Integrating societal processes to accommodate social processes and planning, and the case of bioenergy." *Ecological Economics*, 104, pp. 22–32.

Spangenberg, J. H. (2015) "Sustainability and the Challenge of Complex Systems." In J. C. Enders, M. Remig (eds.), *Theories of Sustainable Development*. Routledge, Abingdon, Oxford, UK, pp. 89-111.

Spangenberg, J. H. (2016) "The world we see shapes the world we create: how the underlying worldviews lead to different recommendations from environmental and ecological economics – the green economy example." *International Journal of Sustainable Development*, 19(2), pp. 127–146.

Spangenberg, J. H. (2018) "Behind the Scenarios: World Views, Ideologies, Philosophies. An analysis of hidden determinants and acceptance obstacles illustrated by the ALARM scenarios." *Sustainability,* 10(7), p. 2556.

Spash, C. L. (2007) "The economics of climate change impacts à la Stern: Novel and nuanced or rhetorically restricted." *Ecological Economics,* 63(4), pp. 706-713.

Stephens, J. C. (2013) *Time to Stop CCS Investments and End Government Subsidies of Fossil Fuels*. WIREs Climate Change.

Stern, N. H. (2006) *The Economics of Climate Change. The Stern Review*. Cambridge/New York: Cambridge University Press.

Syll, L.P. (2010) "What is (wrong with) economic theory?" *real-world economics review*, 55, pp. 23-57.

Trainer, T. (2008) "A short critique of the Stern Review." *real-world economics review*, 45, pp. 54-58.

Umweltbundesamt (2018a) The WORLD Model Development and The Integrated Assessment of the Global Natural Resources Supply. UBA Texte 100/2018, Federal Environment Agency, Berlin

Umweltbundesamt (2018b) System analysis for environmental policy – System thinking through system dynamic modelling and policy mixing as used in the SimRess project "Models, potential and long-term scenarios for resource efficiency" (SimRess). UBA Texte 49/2018, Federal Environment Agency, Berlin.

UNFCCC United Nations Framework Convention on Climate Change (2015) The Paris Agreement, UNFCCC doc no. FCCC/CP/2015/L.9/Rev.1. Paris, UNFCCC.

van der Sluijs, J. P. (2012) "Uncertainty and dissent in climate risk assessment: a post-normal perspective." *Nature and Culture*, 7(2), pp. 174-195.

Victor, P. A. (2012) "Growth, degrowth and climate change: A scenario analysis." *Ecological Economics*, 84, pp. 206-212.

Wachsmuth, J., Duscha, V. (2019) "Achievability of the Paris targets in the EU—the role of demand-side-driven mitigation in different types of scenarios." *Energy Efficiency*, 12(2), pp. 403-421.

Yager, R. R., Filev, D. P. (1994) *Essentials of fuzzy modeling and control.* New York: John Wiley.

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