Challenges in Sustainability

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Cover image
Traditional paddle boat, Mui Ne, Vietnam
Photographer: Reto Furrer

About *Challenges in Sustainability*

Objectives

Challenges in Sustainability (CiS) is an international scientific journal dedicated to the publication of high-quality research articles and review papers on all aspects of climate/global change and transitions towards sustainability. The objective of the journal is to publish important and path-breaking original science in these fields which stimulates the development of solutions in an era of climate and development crisis. System oriented views which integrate relevant issues and help to learn from singular cases are preferred. All manuscript needs to be prepared in English and will undergo a rigorous peer review process. It is the aim that all papers will immediately appear online after acceptance.

Topics to be covered by this journal will include, but are not limited to:

- Environmental and Resource Science
- Climate and Global Change
- Solutions for the Climate Crisis
- Sustainable Cities
- Overexploitation of resources
- Carbon accounting
- Efficiency of carbon offsetting
- Transition Options and Transformation pathways
- Earth System and Integrated Modelling
- Climate Change and Development Economics
- Sustainable Development
- Impact Assessment
- Remote Sensing and Geoinformation

Aims & Scope

The journal defines its place at the interface between natural, socio-economic science and aims to provide a platform which helps to establish systematic analyses on global and climate change problems, associated solutions and trade-offs. In this regard the journal will establish an academic discipline which paves to road towards a deeper understanding of sustainability changes, for option finding and problem solving. Thus, it bridges gaps between disciplines and science and stakeholders while not neglecting scientific rigorousness and excellence. The journal promotes science based insights of the coupled man-environment dynamics and is open for innovative approaches that stimulate scientific and political debates.

Challenges in Sustainability

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Editorial

Sustainability: A Path-breaking Idea, but Still Associated with Huge Challenges

Juergen Peter Kropp

Potsdam Institute for Climate Impact Research (PIK), Telegraphenberg A 31, 14473 Potsdam, Germany;
E-Mail: kropp@pik-potsdam.de

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Sustainability science is a young discipline that started emerging in the late 20th century, although Hans Carl von Carlowitz had already introduced ideas about sustainable management of forests in the early 18th century. In recent times, the Club of Rome report in 1972 and the Brundtland report in 1987 developed these concepts further, and subsequently the sustainability idea became prominent in political debates as well. In both reports it was recognized that growth would have certain limits and a different style of resource utilization was therefore necessary. However, despite numerous approaches dealing with sustainability, it is still an important issue.

Nowadays humanity increasingly interferes with natural systems on a planetary scale. This holds for many subsystems of the Earth including the climate, soil and water bodies, and marine systems. During the 20th century, rapid technological development and demographic pressure advanced to a degree that we caused radical and unintended changes in the Earth's integrity. This is observable in certain subsystems, for example in the atmosphere (global warming), in marine systems (overexploitation of fish stocks), or in soils (degradation). One crucial element of sustainability is the capacity of natural resources to sustain human demands. It is foreseeable that parts of the system are overburdened beyond their capacity. This holds likewise for waste disposal, as for the atmosphere (greenhouse gases) and the utilization of resources like ores and renewables like trees and fish. To sum up, one can state that the overexploitation of natural resources and economic growth causes environmental impacts which may lead several systems to the brink of collapse. In other words, humanity causes a multitude of problems and most of them are not grounded in one sector, region, either can they be described by one scientific discipline.

Thus, sustainability science is a discipline that can be placed as the one at the meeting point of different scientific disciplines. However, during the last four decades, science made remarkable progress in regard to an assessment on how climate and global change will affect livelihood conditions, and how humanity is accelerating the above mentioned changes. The question is how we can avoid certain human activities that destroy the functionality of certain subsystems of the Earth and how we can develop potential solutions. It is a major challenge to understand the dynamics of man-made environment systems as a basis for the development of sustainable transition pathways in the sense of planetary engineering and management. In other words, sustainability science addresses the man-made environment interface.

Although all these points have been well-known for decades, we need to ask why it is so difficult to achieve pathbreaking scientific results, which may help us to develop clear visions of real sustainable development. It is well-known that resource consumption is an accompanying factor of economic prosperity and global resource consumption is still steeply growing. In some countries we observe—mainly the advanced ones—that resource consumption stabilizes or even decreases, while their high material intensity is still managed by exporting it to developing countries. Thus, the challenge to decouple resource consumption from economic development remains, and it is not only a question of a green economy, technological progress, or how natural resources are being utilized. It is indeed also a societal challenge. Human lifestyle changes might be a further catalyst for making headway towards sustainability. Nevertheless, current progress into this direction is slow, moreover, in large parts in the developing countries, we can see a tendency just to copy westernized lifestyles. A real innovation for the world would be a strategic approach for a sustainable economy that results in social equity and fairness, risk resilient livelihood conditions, sustainable resource use, and the avoidance of ecological scarcities—all these under consideration of planetary boundaries.

Nevertheless, sustainability is still an elusive concept. It is hard to define what sustainability really implies in terms of environmental constraints or societal development, in particular on a regional scale. Consequently, at the beginning of the 21st century, scientific bodies called for a more systematic sustainability science, e.g. International Council for Science defined sustainability as a major goal in its research strategies. Despite these efforts, concepts still lack real meaning. Thus, the aim should be to underpin activities dealing with the general aspects of sustainability with stronger and sounder scientific concepts. Questions, like: what exactly is sustainability? How can we achieve sustainability targets? And, what does 'being sustainable' mean? need to be in the foreground. Thus, sustainability science is environmental systems science.

Although all these points have been intensely discussed in recent decades, a thrilling and demanding journey still lies ahead for sustainability science. In regard to methodological terms, we need to encompass the different magnitudes of scales in terms of time, space and functions. Thus, sustainability science still invokes a lot of questions, i.e. we have to tackle, in particular, the following three challenges: 1) The provision of a methodological arsenal that allows the description and analysis of questions of sustainability in a comparable and transferable manner, i.e. we permanently have to ask ourselves what we can learn from singular cases in terms of the overarching sustainability challenge; 2) Options for solutions at different levels, e.g. regional and global, need to be assessed systematically in order to develop pathways which allow us to achieve predefined environmental targets, like the 2 °C target agreed in the Copenhagen Accord 2009; 3) As a lot of strategies are included under the term 'sustainability', there is a need to develop a concept which allows assessment and measurement of success of implemented sustainability measures.

However, sustainability itself is a challenge, because it needs ethical decisions from humankind itself whether we want to live in a safe environment or not. But how we achieve these safe limits is an issue of sustainability science, i.e. in terms of how to achieve these limits and what potential trade-offs there might be. The new journal Challenges in Sustainability provides a perfect platform for these goals.

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Challenges in Sustainability

Research Article

Why 'Sustainable Development' Is Often Neither: A Constructive Critique

Alexander Lautensach [1,]* and Sabina Lautensach [2]

[1] School of Education, University of Northern British Columbia, 4837 Keith Ave. Terrace, B.C. V8G 1K7, Canada; Tel.: +1 250 615 3334; Fax: +1 250 615 5478; E-Mail: alex.lautensach@unbc.ca
[2] Human Security Institute,1025 Farkvam Rd. Terrace, B.C. V8G 0E7, Canada

* Corresponding author

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Abstract: Efforts and programs toward aiding sustainable development in less affluent countries are primarily driven by the moral imperative to relieve and to prevent suffering. This utilitarian principle has provided the moral basis for humanitarian intervention and development aid initiatives worldwide for the past decades. It takes a short term perspective which shapes the initiatives in characteristic ways. While most development aid programs succeed in their goals to relieve hunger and poverty in ad hoc situations, their success in the long term seems increasingly questionable, which throws doubt on the claims that such efforts qualify as sustainable development. This paper aims to test such shortfall and to find some explanations for it. We assessed the economic development in the world's ten least affluent countries by comparing their ecological footprints with their biocapacities. This ratio, and how it changes over time, indicates how sustainable the development of a country or region is, and whether it risks ecological overshoot. Our results confirm our earlier findings on South-East Asia, namely that poor countries tend to have the advantage of greater sustainability. We also examined the impact that the major development aid programs in those countries are likely to have on the ratio of footprint over capacity. Most development aid tends to increase that ratio, by boosting footprints without adequately increasing biocapacity. One conceptual explanation for this shortfall on sustainability lies in the Conventional Development Paradigm, an ideological construct that provides the rationales for most development aid programs. According to the literature, it rests on unjustified assumptions about economic growth and on the externalization of losses in natural capital. It also rests on a simplistic version of utilitarianism, usually summed up in the principle of 'the greatest good for the greatest number'. We suggest that a more realistic interpretation of sustainability necessitates a revision of that principle to 'the minimum acceptable amount of good for the greatest sustainable number'. Under that perspective, promoting the transition to sustainability becomes a sine qua non condition for any form of 'development'.

Keywords: conventional development paradigm; human security; overshoot; sustainable development; utilitarianism

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1. Introduction

Following the dominant convention in the literature, we define development as multidimensional innovation or growth that achieves positive outcomes for the quality of human lives and/or for human security. It can manifest in the areas of financial income, employment, distribution of wealth, education, political autonomy, basic needs for survival, health of populations and ecosystems, equality, self-esteem and dignity, and freedom [1]. The latter includes Sen's [2] standard of individual capability. Those areas cover people's social, biological, and economic environments and have been recognised as the main indicators contributing to the human development index [3] and human security index [4]. Sustainable development, then, includes any such innovation or growth that does not compromise the ability of future generations to develop along the same lines ([5], p. 2). This corresponds to the definition by the World Conservation Union (IUCN), "improving the quality of human life while living within the carrying capacity of supporting ecosystems" ([6], p. 6). Thus, sustainability is all about avoiding to transgress systemic limits.

The above listed areas in which development can manifest suggest directly some ethical reasons why affluent countries engage in international development aid: When the citizens of a poor country suffer deprivations in those areas, and their own government and communities are not in a position to alleviate their situation, international aid seems indicated for several moral reasons. One of those reasons, though rarely explicated, is self interest. Helping a country develop into a valuable trading partner and enabling that country to purchase goods and services from the donor country (so-called tied aid) are in the obvious national self interest of the donor. The Paris Declaration on Aid Effectiveness [7] paved the way for development aid to become untied, broadly coordinated among donors, and designed and implemented by the recipient countries. But oftentimes political and strategic considerations still dominate the allocation decisions [8].

Much more widely advertised is the utilitarian motivation, under which helping a sufficiently large group of people transcend a situation that caused them to suffer inordinate deprivations, at only minor sacrifice to the donor, provides the necessary and sufficient justification for aid. Likewise, deontological and virtue-based ethics recognise a duty to relieve suffering, often manifesting in the mission statements of charitable organisations both religious and secular. Arguments in support of that duty often invoke human rights and basic needs. In practice, such humanitarian motives tend to focus on situations where the deprivation is most easily quantified, as in cases where populations experience extreme poverty, unemployment, under-education, poor health, or homelessness.

The basic and widely shared agreement underlying these ethical motives is that knowledge of human suffering implies a duty to actively help. Much less general agreement is found when it comes to choosing the most appropriate ways to help. Short term relief measures dominate in cases of natural disasters such as the 2010 Haiti earthquake which displaced about 2.3 million Haitians (almost one quarter of the total population) and killed or injured over half a million. The UN's relief program focuses on the restoration of the island's economy and public health [9].

Designed as immediate disaster relief, it largely ignores how the island's climate, soil conditions, environmental trends, and population dynamics constrain its long term prospects for development. Those issues are considered beyond the program's time horizon and beyond its goals of providing immediate relief. In other words, international disaster relief is seldom justified by arguments invoking sustainability, nor would many suggest that it needs to be. This sets it apart from international development aid where the absence of a long-term focus can raise considerable problems, as we will explain presently.

2. Disaster Relief and Development Aid

The short term humanitarian priorities in disaster relief often seem relatively straightforward, suggesting unequivocally not only the need for immediate action but also what choices of aid measures might be indicated. Yet, as soon as the time frame is extended to the medium and long term, those choices become more debatable. This is most evident in cases of famine relief. For example, Peter Singer [10] considers the relief of human suffering to be a paramount moral duty; he argued that a famine always demands immediate food aid from any who are reasonably able. Arguing on the same humanitarian and utilitarian grounds, Garret Hardin [11] comes to the opposite conclusion, that famine relief in the form of food donations would be the worst anybody could do to a poor country. Because it promotes population growth without addressing the reasons for the famine, it will only cause worse famines in years to come. Both Singer and Hardin agree that family planning and contraception programs must be included in any such relief program. Curiously, neither author engages with deontological or virtue-based rationales for aid, which emphasise the charitable act as a duty independent of consequentialist considerations.

The difference between the two positions lies of course in the time frame and the preferred balance between the strategies of short-term alleviation versus long-term prevention. As it turns out, Singer's view usually carries the day with many relief programs, except that family planning is seldom included as an integral part [12,13]. That omission again underscores the short term perspective taken by such programs. Yet the conflict between the two strategies points to an ethical dilemma. One wonders just how severe the suffering and misery must be before we ought to ignore potential long-term complications, or how disastrous the long-term consequences of the relief action must be to justify the withholding of aid.

In the case of disaster relief we see no room for justifiable compromise; its concerns lie by definition in the short term, amounting to moral blinkers. The challenge of finding appropriate compromises becomes much more pressing where it regards programs for development aid which pursue explicit aims that extend into the medium and long term future. We would expect such programs to be guided primarily by considerations of long term benefits which would logically include sustainability if the time horizon is not specified. Thus, as long as the goals of a development program are not delimited in time, that development is automatically governed by the constraints of sustainability. Conversely, a program or initiative that promotes evidently unsustainable end states should come with clear temporal demarcations and disclaimers abrogating any responsibility for consequences that might ensue beyond those dates. We base those expectations on the ideals of beneficence and veracity that inform the professional codes of conduct of development workers and academics. In this study we examined to what extent major development programs live up to those expectations.

3. Method

Among the many programs at the national and international levels that all share the label of sustainable development, international development aid tends to benefit from a supranational perspective and a grounding in scientific analyses of needs and potentials. Rather than attempting to gauge the successes of individual programs we chose to examine the cumulative and synergistic outcomes occurring in their most deserving recipients, the world's poorest developing countries. We selected our sample countries on the basis of their rankings on the Human Development Index [3] and the Human Security Index [4]. Countries that scored low on both indices not only receive rather a lot of development aid, in many cases they represent situations that render development fundamentally imperative on humanitarian grounds. Development in this case is hardly a whimsical option but the only defensible course of action. Yet, unlike disaster relief, these programs explicitly pursue long-term goals. The question is: what shape do their strategies take, stopgap or long term?

In order to maximise the chances of those development efforts to achieve their objectives we excluded from our sample of poorest countries any that showed a failed states index (FSI) greater than 100, which includes the top thirteen [14]. Failing states are unlikely to provide the minimum requirements of infrastructure and political stability for successful development. In other words, they need more than the average kind of development aid, ranging from peace keeping to broad social reform, often supported by armed intervention. Because of recent destabilising developments, Mali was omitted from the sample in the revised version of this paper.

A program for sustainable development based on a genuine long term perspective would seek either to ensure the sustainable flourishing of the economy and of human well-being, or to pave the way for a smooth transition towards more sustainable structures and practices. The extent to which a country operates sustainably can be estimated by comparing its citizens' average ecological footprint (reflecting its demand of resources and its ecological impact) with the amount of biocapacity available for each citizen (reflecting its resources and ecosystem services, also referred to as natural capital) [15-17]. Based on a previous report [18] we use the country's sustainability quotient or SQ—the ratio of per capita ecological footprint over its available per capita biocapacity. An SQ of less than 1 indicates sustainability while greater than one indicates ecological overshoot [19]. The data are summarised in Table 1.

To assess the development of the sample countries for its sustainability we identified a major development aid program for each country, verified that it explicitly named sustainable development among its aims, and examined its major strategies for their effects on the country's biocapacity factors (bioproductive area and bioproductivity) and on its ecological footprint drivers (population growth, consumption of goods and services per person, footprint intensity; [19], p. 41). The sum of those effects would cause its SQ to either rise or fall. The trend by which the SQ changes over time indicates how sustainable the development of a country or region is, and whether the risk of ecological overshoot is increasing or decreasing. Where possible we selected grant programs over loan programs as the former contribute to Third World debt which itself contributes significantly to unsustainable practices (such as the replacement of food crops with exportable cash crops). The findings are summarised in Table 2.

Table 1. Eleven of the world's poorest countries are compared to the European Union and the world average in their extent of sustainability. Example: Each citizen of Eritrea uses the equivalent of 0.9 global hectares to sustain their livelihood; the country of Eritrea has 1.6 global hectares of bioproductive land to offer to each citizen; this results in an SQ of 0.563, meaning that Eritreans live within the carrying capacity of their land. Sources: [19,20].

Country	Ecol FP (gha per person)	Biocapacity (gha per person)	SQ	HDI ranking Max = 187	HSI ranking Max = 232
Burkina Faso	1.3	1.3	1.0	181	210
Burundi	0.9	0.5	1.8	185	225
Eritrea	0.9	1.6	0.563	177	218
Ethiopia	1.1	0.7	1.571	174	221
Guinea-Bissau	1.0	3.2	0.31	176	208
Liberia	1.3	2.5	0.52	182	229
Mozambique	0.8	1.9	0.421	184	198
Niger	2.3	2.1	1.10	186	222
Rwanda	1.0	0.6	1.67	166	220
Sierra Leone	1.1	1.2	0.92	180	224
Togo	1.0	0.6	1.67	162	219
European Union (27)	2.7–8.3 Eur. Av. 4.8	1.0–12.5 Eur. Av. 2.2	0.494–6.023 Eur. Av. 2.2	3–55	2–71
World	2.7	1.8	1.5	1–187	1–232

4. Finding: 'Sustainable Development' Is Often Neither

Table 1 lists the state of sustainability in eleven of the world's poorest countries, compared to the EU and the world average. The distribution of SQ values shows six countries operating sustainably—i.e. drawing only on the interest from their natural capital. The other six have exceeded their sustainable limit and are drawing on both principal and interest. Yet only four of those SQ values match the world average, and none of them comes close to the kind of overshoot exemplified by the European average of 2.2 (2003) or the US value of 2.1 (2007) [20].

The data confirm our earlier findings on South-East Asian countries [18], as well as global surveys [20], namely that poor countries tend to have the advantage of greater sustainability except in cases of excessive population size. In those cases ecological overshoot occurs in spite of small per capita footprints because the biocapacity resources are shared among too large a population, resulting in rampant poverty, often aggravated by post-colonial legacies of inequitable power structures and mismanagement. Those examples (in our sample, Burundi, Rwanda and Togo, and to a lesser extent Ethiopia) show that the SQ says nothing about a country's level of development; it only indicates how sustainably it operates.

In contrast to those high SQ countries, many developing countries with smaller populations show considerable potential to achieve the transition to a sustainable economy, aided by the fact that their natural capital has not yet been greatly reduced [19]. In our sample, those would be Niger and Burkina Faso. Suitable development aid could provide crucial support at the right time to make that transition possible before further population growth removes it beyond the horizon.

The remaining countries in our sample (Eritrea, Guinea-Bissau, Liberia, Mozambique, and Sierra Leone) show SQ values below 1.0, indicating that they are conducting their affairs sustainably for the time being. This encouraging finding needs to be evaluated in the light of the abject poverty that abounds in all of them. This means that the state of sustainability represents only one of several necessary conditions for human security and well-being. Moreover, their low SQ does not necessarily indicate that these countries have more resources to offer those poor multitudes; more likely their excess productivity is exported abroad to support other countries' overshoot. Yet, low SQ also indicates a significant opportunity for development aid—the chance that with the right kind of support those countries could remain sustainable while still relieving their poverty. The question is: are they likely to receive such support?

This leads to the problem posed by the dynamics of the situation. The SQ values in Table 1 only provide snapshots in time; they say nothing about the directions in which those countries are developing. An indication about probable changes for each country is given by its major source of development aid. Table 2 lists one major donor program for each country in the sample, along with its stated goals and the resulting ramifications on footprints and biocapacities. The data suggest a slim chance for an affirmative answer to the question raised in the preceding paragraph.

Table 2: For each of the eleven countries listed in Table 1, a major source of development aid is examined for its goals and its objectives regarding footprint and biocapacity. In cases where no explicit objectives were given, probable consequences are stated. Sources are: a) Burkina Development Partnership. http://www.burkinadevelopmentpartnership.org/index.php?id=4 (accessed on 2 March 2013); b) Burundi: Development & Cooperation – Europeaid. http://ec.europa.eu/europeaid/where/acp/country-cooperation/burundi/burundi_en.htm (accessed on 2 March 2013); c) Eritrea – UN Development Assistance Framework. http://www.er.undp.org/un_eritrea/docs/undaf_pub_eritrea.pdf (accessed on 2 March 2013); d) Development Without Freedom. http://www.hrw.org/sites/default/files/reports/ethiopia1010webwcover.pdf (accessed on 2 March 2013); e) Ethiopia: Sustainable Development and Poverty Reduction Program (SDPRP). http://siteresources.worldbank.org/INTPRS1/Resources/Ethiopia_APR2-PRSP(March2005).pdf (accessed on 2 March 2013); f) Guinea-Bissau: Development & Cooperation – Euopeaid. http://ec.europa.eu/europeaid/where/acp/country-cooperation/guinea-bissau/guinea-bissau_en.htm (accessed on 2 March 2013); g) Document de stratégie pays et programme indicatif national pour la période 2008-2013. http://ec.europa.eu/development/icenter/repository/scanned_gw_csp10_fr.pdf (accessed on 2 March 2013); h) History of USAID in Liberia. http://liberia.usaid.gov/node/82 (accessed on 2 March 2013); i Projects of Germany. http://41.220.166.65/reports/donors/12 (accessed on 2 March 2013); j)Commission proposes to gradually resume development aid to the Republic of Niger. http://europa.eu/rapid/pressReleasesAction.do?reference=IP/10/1004&format=HTML&aged=0&language=EN&guiLanguage=en (accessed on 2 March 2013); k) Country Context. http://web.undp.org/evaluation/documents/ADR/ADR_Reports/Rwanda/ch2-ADR_Rwanda.pdf (accessed on 2 March 2013); l) DFID Sierra Leone – Operational Plan 2011-2015. http://www.dfid.gov.uk/Documents/publications1/op/sierra-leone-2011.pdf (accessed on 2 March 2013); m) Togo Country Strategy Paper 2011-2015. http://www.afdb.org/fileadmin/uploads/afdb/Documents/Project-and-Operations/Togo-CSP%202011-2015%20(3)%20Full%20Final.pdf (accessed on 2 March 2013).

Country	Major Source of Development Aid	Goals of Development Program	Stated objectives regarding footprint	Stated objectives regarding biocapacity
Burkina Faso	BF Development Partnership	Basic education, Small business development	'Get out of poverty'	None
Burundi	European Development Fund (EDF)	'Rural rehabilitation, health and general budget support'; agricultural development	'Reduce poverty and return to sustainable development'	Biodiversity and environmental quality are included among aims
Eritrea	UN Development Assistance Framework (UNDAF)	Basic social services; MDGs; food security; 'emergency & recovery'; gender equity;	'Enhance productivity, export expansion, and trade and investment in high potential growth sectors'	MDG 7: environmental sustainability is mentioned but not explained
Ethiopia	World Bank SDPRP; Ethiopia is a major recipient of aid; also a major failure;	Agricultural growth and food security; accelerating private sector growth; strengthening of public institutions	Economic growth is emphasized	Agricultural productivity to increase; but food aid hinders.
Guinea-Bissau	European Development Fund (EDF)	Infrastructure development, conflict prevention, water safety, energy sources, economic growth	Most objectives contribute to an increase of the footprint	Strengthening biodiversity in the coastal region is among the projects

Table 2: *Cont.*

Country	Major Source of Development Aid	Goals of Development Program	Stated objectives regarding footprint	Stated objectives regarding biocapacity
Liberia	USAID	Sustainable development in political structure and education, agriculture, infrastructure & energy	Most objectives appear neutral toward the footprint	Renewable energy sources are to be developed
Mozambique	Germany—Federal Ministry for Economic Cooperation and Development	43 projects on education, administration, HIV/AIDS control, transport & infrastructure, 'sustainable economic development'	Increase of emissions is likely	Improved education likely to decrease reproductive rate;
Niger	EuropeAid—European Development Fund (EDF)	Health care, transport, social protection & development (small business)	Improved roads are likely to result in increased emissions	Reproductive health and rights are likely to decrease population growth
Rwanda	World Bank	MDGs, national reconciliation, economic growth, poverty reduction, increased life expectancy	Most objectives contribute to an increase of the footprint through increased consumption	High population density and environmental deterioration are not being addressed
Sierra Leone	UK—Department for International Development	'Macroeconomic stability', increased revenue base, increased foreign investment, economic growth	Footprint is likely to increase significantly	None
Togo	African Development Bank & African Development Fund	Good governance; infrastructure; regional trade; agricultural sector	Road building is likely to increase emissions; 'economic growth' to increase footprint	Agricultural productivity to increase

Even considering that each country receives aid from multiple other donors, the data indicate that these particular donors have not fully understood the challenge. Of even greater concern is the fact that if development aid tends to fail in the cases of those sustainable countries by not preventing them from slipping into overshoot, it is even less likely to succeed in the cases of unsustainable countries in helping them reduce it. This reinforces critiques that point to widespread failures of development aid in other areas besides sustainability [21].

The findings also raise the question about the possible impact that this development aid could have on the sample countries, in relation to their own domestic investments. For the countries with SQ values greater than 1.0, the total development aid received in 2011 ranges from 3.5% of GDP (Ethiopia) to 10.8% of GDP (Burundi) [22,23]. For the countries in the sustainable group those percentages range from 3.8 (Eritrea) to 8.1 (Sierra Leone), except for Liberia which received aid amounting to 35.9% of GDP. In the latter case certainly the specific development projects sponsored by the aid can be expected to exert a significant effect on the future state of sustainability status of the entire country. But even for the other countries in the sample the lower impact of aid does not mean that its effects will be negligible.

The main issue addressed by this paper, however, is not the projected impact of aid but to what extent aid projects labeled as sustainable development deserve that label. Having established that sustainability is hardly prevalent among the probable outcomes of the development programs in our sample, the question arises to what extent unsustainable development can or should qualify as development at all. Given our definition in the introductory paragraph, development that is not sustainable would reduce the ability of future generations to develop further in the same areas as are currently envisioned. A historical example for this situation is the early history of Cyprus where the resident population developed the island's abundant copper deposits by fuelling their smelters with the island's pine forests. Today Cyprus shows neither a viable copper industry nor any substantial pine forests [24].

Contemporary examples of unsustainable 'development' include the numerous incidences of regional ecological overshoot where populations demand more resources and services than their region can sustainably deliver. The inevitable consequence is that future generations will find their options reduced in terms of some or most of the ten areas of development we referred to earlier: financial income, employment opportunities, distribution of wealth, education, political autonomy, basic needs for survival, health of populations and ecosystems, equality, self-esteem and dignity, and freedom [25]. Fully half of our sample countries fall into that category. A well known global example is the explosive expansion of petroleum-based industries over the past century, bound to run its course within the next few decades and to be entered in history as the peak oil phenomenon [26-28]. While it lasted it brought unprecedented affluence and comfort to much of humanity; however, its negative long term consequences are likely to complicate the lives of many future generations. Whether peak oil should be regarded as development in the sense of our definition depends entirely on the observer's time frame. We must conclude that over the long term no development in the true sense will happen in those examples. Only over short terms can unsustainable practices qualify as development, if at all.

Ignoring the risk of tautology, authorities have invoked 'sustainable development' as a guiding concept at least since the Brundtland report [29]; certainly no administration would admit to its development policies as being unsustainable. But in order to avoid the tautology, development needs to be understood as any measure that furthers the transition to sustainability, to a more inclusive respect for grantable human rights (that includes future generations) [30], and a general commitment to the non-violent resolution of conflicts.

The stated goals of the programs listed in Table 2 generally emphasise poverty reduction through economic growth. Poverty provides the motive while economic growth is their remedy of choice. Thus these programs represent chimaeras of disaster relief and development aid, set on alleviating an objectionable situation without too much concern about the long term implications of continuing growth, or about any limiting variables that may create additional problems over the long term. This raises the question how so many well-paid, highly educated experts can persist in recommending such erroneous courses of action while any substantial progress towards sustainability continues to elude us.

5. Why Is Sustainable Development So Rare?

The finding that very few countries in our sample are moving towards sustainability according to this analysis (Burundi, Liberia, and possibly Mozambique appear to qualify) seems tragic though not entirely unexpected. Too many development program documents seem to promise everything to everybody, resembling election propaganda more than genuine plans towards the enduring welfare of humanity. The language of the UN document on indicators of sustainable development is devoid of any reference to limits [31]. Another example are the UN's Millennium Development Goals [32], listed in Table 3. Likewise, the Rio+20 United Nations Conference for Sustainable Development revealed a curious combination of multidisciplinary analysis and inattention to limits [33]. This widespread bias toward wishful thinking has ideological origins, which we will examine presently.

Table 3. The Millennium Development Goals and Current Accomplishments ([32,35], adapted from [37]).

Goals	Current accomplishments
Goal 1: Eradicate extreme poverty and hunger	On track to reach below the target of 23% poverty rate
Goal 2: Achieve universal primary education	Some countries on track, others behind
Goal 3: Promote gender equality and empower women	Some progress in education, little in employment and political representation
Goal 4: Reduce child mortality	Some regions on track, most developing countries behind
Goal 5: Improve maternal health	Largely behind
Goal 6: Combat HIV/AIDS, malaria and other diseases	Largely behind on HIV and malaria, on track for TB
Goal 7: Ensure environmental sustainability	Far behind, despite vague definitions
Goal 8: Develop a Global Partnership for Development	Mostly on track but definitions are confusing and contradictory

Following Singer's view [10], the MDGs emphasise the eradication of poverty and disease as implicit moral duties. However, explicitly those goals are framed as fulfilling an entitlement, the right to enjoy 'freedom from want' [34]. As we elaborated elsewhere [25], the problem with such a right, while everyone is of course free to claim it, is that no authority could grant it to the more than seven billion people inhabiting this planet at this time. The fact that the MDGs make no mention of limits to growth implies a worldview that considers business as usual not as problematic but as extendable into the indefinite future. Only someone who believes that the Earth's resources are unlimited can regard their allocation as a universal right for an indefinitely large population; and only someone who believes that the world's population and its impact have not even come close to the Earth's carrying capacity will consider the goal of eradicating epidemics to be realistic. In addition to this fundamental flaw, the MDGs have been hampered by a lack of political commitment and consensus, and by the worldwide economic slowdown [35]. As Table 3 indicates, most of the MDGs are not being achieved by their target date of 2015. Instead they are to be replaced by a new set of goals, called Sustainable Development Goals (SDGs), to be formulated by September 2013 [36].

An explanation for this discrepancy between wishful thinking and practical failure must take into account the diversity of beliefs, values, and ideals—often summarised as ideologies—that inform people's notions of what constitutes progress [38]. Sometimes those notions create what Ronald Wright ([39], p. 8) referred to as 'progress traps'. Of particular importance are those beliefs that delimit the realm of the possible. An obvious example is cornucopianism, the belief that the growth of populations and economies is not subject to physical limits [40]. Under the cornucopian delusion, progress takes a very distinct shape of unending growth in human numbers, their consumption, and the quality of their lives. The absence of any scientific justification for this belief has relegated it to the realm of implicit yet powerful assumptions that still inform certain schools of academic thought such as neoclassical economics [41,42].

Some of the listed programs for sustainable development seem indicative of cornucopianism. At least they do not explicitly acknowledge limits to growth or local overshoot, nor do they tend to take into account global environmental change resulting from the present situation of global overshoot. Many rely on economic growth (usually measured as GDP increase) as a means to raise income levels and provide trickle-down benefits from investment, the large-scale extraction of non-renewable resources to boost employment and trade balance, and converting from subsistence agriculture to staple industries for export. Those policies are supported by a trust in global trade relationships and an optimistic outlook on the potential of market forces, complemented by some regulation, to rectify global inequities and to eliminate poverty worldwide. The future is envisioned as a repetition of the past, only more of it. Raskin et al. [43] referred to this ideology as the Conventional Development Paradigm (CDP).

The well-publicised manifestations of the global environmental crisis (under the broad phenomena of climate change, pollution, resource scarcity, and the loss of biodiversity), as well as the abundant evidence for its anthropogenic causation, render the CDP a rather unrealistic kind of long term thinking. This is the kind of perspective that still moves people to welcome the discovery of new oil deposits as good news; without the denial of anthropogenic climate change such news would be received with ambivalence at best. It is also unrealistic because it assumes that the same institutions, regimes, and ways of thinking that undoubtedly contributed to the global environmental crisis are able to help us transcend it. This assumption can only be upheld if one denies or disregards the true extent of the crisis. It makes for an overly simplistic, laissez-faire type interpretation of sustainability that contradicts the bulk of the evidence reported by environmental scientists.

While those ideological deficiencies provide a plausible explanation for the failures of the MDGs and related development efforts, they do not explain their sporadic successes, and they offer little help towards finding ways out of the conundrum. Most of the development programs listed here derive their support partly from sources that are not as readily quantified as is bioproductivity—human ingenuity and spirit, social capital, and potential for learning. Also, ecological overshoot can proceed for quite some time without the loss of natural capital necessarily causing any immediate calamities [44]. Thus, development that is unsustainable can continue sometimes for generations before collapse becomes imminent. This undoubtedly contributes to the slowness of the collective learning process, as do a diverse assortment of counterproductive myths, cognitive biases, moral ineptitudes, and mental habits, all well characterised in the literature on what might be summarised as 'human nature' [38,45-48].

6. A Utilitarian Theory of Development that Humanity Can Live With

The contingencies of overshoot render it unlikely that the problems associated with underdevelopment can be effectively remedied by efforts that only focus on 'eliminating poverty' as the humanitarian ideal demands—regardless of how one defines poverty [49,50]. Two reasons conspire towards this obstacle: The first arises from the counterproductive effects of further global economic growth under overshoot; they necessitate that any growth in a poor country be accompanied by restraint in a rich country—a politically unlikely proposition.

The second reason lies in the futility of redistribution efforts; at this point in time, if a global dictatorship allocated exactly equal amounts of resources to every human being, we would still all starve, albeit rather slowly [25]. The fact that our current demand can only be sustainably met by about 1.5 planets means that even assuming perfect equity, at the current consumption level one third of humanity would be consuming part of the food producing 'machinery' itself [19]. People living in more extreme biogeographical regions and latitudes would be hardest pressed. Moreover, population growth would still proceed while food prices rise and fresh water and soils grow scarcer [51]. This means that the redistribution of resources cannot be the sole prescription for food security, even though it would certainly help alleviate some of the worst shortages.

In order to ensure lasting environmental security and acceptable survival [52] for all, humanity must reduce its total environmental impact before nature does this for us in very painful ways and before many more species are lost. This imposes a tragic inversion on the traditional humanitarian agenda of development. What is inverted here is nothing less than the holy grail of utilitarianism, often phrased as 'the greatest good for the greatest number'. Our collective environmental impact, described by the I = PAT relationship [53], clearly indicates a range of solution states encompassing numerous combinations of global population sizes and per capita affluence and technology use; all those solution states are sustainable and include population sizes below the current level (how far below depends partly on how long it will take us to get there). Furthermore, Potter's [52] hierarchy of survival modes suggests that some of those solutions are morally preferable to others (e.g. miserable survival for all at 5 billion vs. acceptable survival for all at 3 billion). Others (e.g. [54,55,12]) have come to similar conclusions. The holy grail of utilitarians now amounts to the minimum acceptable amount of good for the greatest sustainable number. This number is probably no more than about four billion people, and perhaps less than one billion [55-57].

What does this new inverted dictum mean for development aid? The need to reduce our numbers does not only arise from our excessive impact. The growing scarcity of key resources, particularly food and potable water, causes suffering that would be avoidable with a smaller population. Cohen [54,55] framed the challenge of global food security in the analogy of a communal dinner table where some guests go hungry; in his words, the problem can be solved in three ways: (i) prepare a bigger dinner, (ii) put fewer forks on the table, (iii) teach better manners. Ehrlich and coworkers [58] reduced the challenge to a 'race between the stork and the plough'. Others (e.g. [59,60]) indicated that little, if any, room remains to increase food supply (i.e., speed up the plough, or make a bigger dinner), although adherents to the CDP (e.g. in [49]) would disagree. In effect, reducing the global population and changing our 'manners' are probably our only remaining options.

The link between the emancipation and education of women and decreases in reproductive rates seems well established cross-culturally. Several aid programs in our sample include educational components, and even in the MDGs this opportunity has been recognised under goal 3 (Table 3). Yet, as we pointed out earlier, the need for population reduction is rarely acknowledged explicitly. Family planning programs still face the opposition of powerful religious and cultural prejudices, spearheaded by collusive governments [12]. It is also clear that many manifestations of anthropogenic global environmental change proceed much too quickly at this stage for the documented reductions in fertility (or the much invoked demographic transitions to result from them) to effect any significant mitigation. This means that both environmental deterioration and population growth will proceed, albeit perhaps at reduced speeds, towards the inevitable collision point at which time much of international aid will need to take the form of disaster relief.

As for our 'manners', one aspect of development aid that could certainly benefit from revision is the lack of honesty associated with using the label of sustainable development. As we established earlier, development that is truly sustainable must fulfil the requirement of addressing the challenges of population, distributional inequities, and overshoot. In that sense, 'manners' include ethical standards and dominant belief systems that bar the way towards gains in efficiency, restraint in consumption, adaptation to inevitable changes, and conducive structural reforms. In all those directions, too, reformed education can make substantial contributions [38] and pave the way for a proliferation in 'positive deviance' in Parkin's [61] sense. While she applied her norms of 'sustainability-literate leadership' mainly to individuals and sociocultural communities, our conclusions suggest that they would be equally beneficial among the international community.

Such deviance is necessary because it seems clear that development initiatives that are primarily informed by the CDP can only help in the short term (as evident in GDP increases). In the longer term they will do more harm than good by reducing natural capital as evident in decreases of other statistics (e.g. the Inclusive Wealth Indicator, IWI) and increasing humanity's collective impact [62]. Rising GDP and shrinking IWI have been observed with some 'emerging economies' such as Brazil and India. Another case in point is the much acclaimed 'green revolution' that vastly boosted food production during the 1970s. In the short term it relieved shortages and prevented impending famines; in the long term, however, it will be regarded a disaster, as Hardin [11] predicted. The couple of decades of time that it bought us were not used wisely; instead, they were squandered on further growth under the belief that this revolution would never end. Now we are again facing famines—except that our numbers have doubled, our ecosystems are weaker, tens of thousands of species have disappeared, natural resources are further depleted, and global pollution has become worse. No other misadventure of conventional development policy illustrates the failings of the CDP better than this missed opportunity. Its humanitarian goals are rendered unattainable by its obsession with 'economic growth' as a human 'need'. In the light of our earlier conclusions such policies should not qualify as development proper. Not even Sen's [2] more flexible principle of 'development as freedom' is able to accommodate ecological constraints or bring humanity closer to the new utilitarian ideal of minimum acceptable amount of good for the greatest sustainable number.

Utilitarian reinterpretations of development sometimes meet with objections based on human rights [63]. Rights become limited by a partial contradiction in the sense that insisting on some rights (i.e., rights that are not grantable) will create insecurity. In her critique of human rights theory Thomas [64] referred primarily to the enshrining of property rights under human rights law, which can, under conditions of limited resources, work at the expense of disenfranchised minorities. In the light of overshoot certain other human rights seem similarly counterproductive, such as the right to a 'clean environment', 'safe drinking water', or 'adequate nutrition'. Given a large enough global population (today's seven billion plus would qualify) and a single planet at our disposal, no world government could grant such privileges to all. One additional 'right' that has arguably proven not only ungrantable but outright harmful is the right to procreate at will [25].

This need for changing our notions about rights points to those challenges that are situated inside the human psyche. By labeling nature as the non-human 'other', an inanimate heap of 'resources' for the taking, consisting of marvellously useful little automatons just waiting to prove their utility to human endeavours, we ultimately set ourselves up for moral bankruptcy and ecological suicide. What emerges are not just the deeply problematic ramifications of the dominant anthropocentric environmental ethic behind such development schemes as the UN's Millennium Goals, but a thorough revision of what it means to be 'modern' and what constitutes 'progress'.

Besides the obvious need to change our notions about human security, about nature, and about modernity, another internal challenge that is evident from the foregoing is the need to change our value priorities with respect to each other. As ecologies simplify and economies falter, centralised governance and the rule of law will become more tenuous. Thus, global development in the true sense means not only that most of us need to re-learn how to run self-sufficient, resilient local communities. It also means that we exercise compassion for those whom the crisis will have displaced from their homes. On 10 January 2012 the Bulletin of the Atomic Scientist once more reset its Doomsday Clock closer to midnight, citing dangers of nuclear proliferation, climate change, and the failure of political leaders to change 'business as usual' and to “set the stage for global reductions” ([65, p. 3). The ranks of displaced multitudes are certain to swell once rising sea levels have inundated some of the world's heavily populated coastal lands [66]. In the absence of decisive initiative by the

UNHCR that would impart on environmental refugees the status of 'world citizens' (or at the very least accord them full official refugee status) [67], their fate depends on the charity of other countries and on charitable NGOs—which, in the midst of shortages and economic downturns, cannot be taken for granted. Clearly the human conscience represents as important a 'tipping point' as do geophysiological variables. Many of these challenges have been reiterated at the Planet Under Pressure Conference (March 2012) leading up to Rio+20 [68].

Since sustainable development in the true sense must incorporate all of those changes it comes as no surprise that so little of it is in evidence. If the developed world's idealistic efforts at development aid were really motivated by the urge to increase justice, human security, and well-being globally while achieving the global transition to a sustainable world, they would not hesitate to start at the top end and reduce the obscene levels of consumption evident there. In many respects that would be an easier undertaking than encouraging development at the lower end without also promoting net growth. Yet, even if we end up not making use of any of those opportunities we can be assured that sustainability will come our way eventually at the hands of mother nature.

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Challenges in Sustainability

Research Article

Sustaining Welfare for Future Generations: A Review Note on the Capital Approach to the Measurement of Sustainable Development

Thorvald Moe [1], Knut H. Alfsen [1,*], Mads Greaker [2]

[1] Center for International Climate and Environmental Research Oslo (CICERO), P. O. Box 1129, Blindern, 0318 Oslo, Norway; E-Mail: kal@cicero.oslo.no (K.H.A.); Tel.: +47 22858569; Fax: +47 22858751
[2] Research Department, Statistics Norway, P. O. Box 8131, Dep, 0033 Oslo, Norway

* Corresponding author

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Abstract: Measuring sustainable development based on analytical models of growth and development and modern methods of growth accounting is an economic approach—often called the capital approach – to establishing sustainable development indicators (SDIs). Ecological approaches may be combined with the capital approach, but there are also other approaches to establishing sustainable development indicators—for example the so-called integrated approach. A recent survey of the various approaches is provided in UNECE, OECD and Eurostat [1]. This review note is not intended to be another survey of the various approaches. Rather the objective of this paper is twofold: to present an update on an economic approach to measuring sustainable development—the capital approach—and how this approach may be combined with the ecological approach; to show how this approach is actually used as a basis for longer-term policies to enhance sustainable development in Norway—a country that relies heavily on non-renewable natural resources. We give a brief review of recent literature and set out a model of development based on produced, human, natural and social capital, and the level of technology. Natural capital is divided into two parts—natural capital produced and sold in markets (oil and gas)—and non-market natural capital such as clean air and biodiversity. Weak sustainable development is defined as non-declining welfare per capita if the total stock of a nation's capital is maintained. Strong sustainable development is if none of the capital stocks, notably non-market natural capital, is reduced below critical or irreversible levels. Within such a framework, and based on Norwegian experience and statistical work, monetary indexes of national wealth and its individual components including real capital, human capital and market natural capital are presented. Limits to this framework and to these calculations are then discussed, and we argue that such monetary indexes should be sustainable development

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indicators (SDIs) of non-market natural capital, and physical SDIs, health capital and social capital. Thus we agree with the Stiglitz-Sen-Fitoussi Commission [2] that monetary indexes of capital should be combined with physical SDIs of capital that have no market prices. We then illustrate the policy relevance of this framework, and how it is actually being used in long term policy making in Norway—a country that relies heavily on non-renewable resources like oil and gas. A key sustainability rule for Norwegian policies is to maintain the total future capital stocks per capita in real terms as the country draws down its stocks of non-renewable natural capital —applying a fiscal guideline akin to the Hartwick rule.

Keywords: capital approach; indicators; national wealth; sustainable development

1. Introduction

Twenty-five years after the World Commission on Environment and Development (WCED) published the book Our Common Future [3], there is an emerging view in economic literature on sustainable development that one should focus on sustaining well-being per capita in real terms for future generations, and that analyses of measurement and policies should be based on analytical models of growth and development and modern wealth accounting.

Thus, a main message from the Stiglitz, Sen and Fitoussi Report from 2009 is:

> The report distinguishes between an assessment of current well-being and an assessment of sustainability. Current well-being has to do with both economic resources, such as income, and with non-economic aspects of peoples' life (what they do and what they can do, how they feel, and the natural environment they live in). Whether these levels of well-being can be sustained over time depends on whether stocks of capital that matter for our lives (natural, physical, human, social) are passed on to future generations ([2], p. 11).

However, there are other approaches to defining and measuring sustainable development. In a recent report from UNECE, OECD and Eurostat [1] differences of views are described thus:

> One view, referred to as the integrated view, held that the goal of sustainable development is to ensure both the well-being of those currently living and the potential for the well-being of future generations. The second approach is that the concern for sustainable development is properly limited to just the latter.

For a survey of both "economic and non-economic" approaches, the reader is referred to this report.

An illustration of the difference between empirical work based on the integrated approach and work based on the capital approach is whether one should include estimated gross domestic product, GDP, as an indicator of sustainable development or not. According to present national accounting conventions, the use of non-renewable natural resources is not deducted when GDP is estimated. Thus, one may boost GDP by rapidly drawing on such resources, but if the revenues are spent on consumption rather than building up other types of capital, the country in question may be worse off in the medium or longer term as their stock of capital or wealth is reduced. Sustainable indicator sets using GDP based on an integrated approach may thus be misleading to policy makers. GDP is a measure of economic welfare in the short term, but not an indicator of sustainable development.

Finally, the World Bank put forward the view:

> Conceive of development as a process of building and managing a portfolio of assets. The challenge of development is to manage not just the total volume of assets – how much to save versus how much to consume – but also the composition of the asset portfolio, that is, how much to invest in different types of capital, including the institutions and governance that constitute social capital ([4], p. 4).

Instead of using GDP one may use Adjusted Net savings (ANS) as a macro indicator of sustainable development as presented by The World Bank. ANS, also called genuine saving, is defined as national saving adjusted for the value of resource depletion and environmental degradation and credited for education expenditures (a proxy for investment in human capital). Since wealth changes through saving and investment, ANS measures the change in a country's national wealth, see [4].

In section 2 we elaborate on our analytical framework based on the capital approach, and in section 3 we illustrate the current measurement of the economic elements in our model of development with reference to current wealth accounting practices in Norway.

We argue, furthermore, that measures of economic or national wealth in monetary terms have their limits, and one thus needs a few indicators in physical terms of non-economic aspects of development, such as critical elements of non-market natural capital and health and social capital in order to make a comprehensive assessment of whether a country is on a sustainable path.

A main reason for measuring the main elements that drive development over time is to inform policy. In section 4 we illustrate how our analytical framework and SDIs are actually used for policymaking in Norway, which is a resource-producing country with large reservoirs of non-renewable, or exhaustible resources, in its oil and gas sector. Section 5 concludes.

2. The Analytical Framework

In the 1970s economists reacted to the challenge of OPEC and the "doomsday predictions" of the Club of Rome by introducing energy, natural resources and environmental pollution into the neoclassical theory of growth. In the 1990s they reacted to global climate change and the Report of the Brundtland Commission [3] by introducing the same considerations into the theory of endogenous growth.

Economic growth involves a two-way interaction between technology and economic life: technological progress transforms the very economic system that creates it. The purpose of endogenous growth theory is to seek some understanding of this interplay between technological knowledge and various structural characteristics of the economy and society, and how such interplay results in economic development. According to Aghion and Howitt [5], endogenous growth theory is inherently more suitable for addressing the problems of sustainable development than neoclassical theory, because the central question to which endogenous growth theory is addressed is whether or not growth can be sustained. See [5], especially chapter 5.

We take the view that economic development should be evaluated in terms of its contribution to intergenerational well-being. Specifically, we identify sustainable development paths along which intergenerational well-being per capita in real terms do not decline. The idea that movements in wealth should be used to judge the sustainability of development paths was put forward by Pearce and Atkinson [6], who defined sustainable development to be an economic path in which (comprehensive) wealth does not decline. The connections between movements in wealth and changes in intergenerational well-being or welfare were identified independently by Hamilton and Clemens [7] and Dasgupta and Mäler [8]. For further discussions of criteria for sustainable development, see [9-11].

According to [8] welfare is very closely related to what we think of as wealth, as wealth represents the totality of resources upon which we are able to draw to support ourselves over time. From this it is clear that welfare is a forward looking concept in which what counts is not how well off we are today, but our prospects for being well off in the future. In other words, welfare is an intertemporal concept.

As for well-being, there seems to be no single definition, and there remains a considerable debate regarding its determinants. Some use it synonymously with welfare. Others, including Dasgupta, claim that well-being encompasses welfare but goes beyond it to include benefits derived from things other than consumption, for example human rights. While the formal distinction may continue in academic debates, it is not of great importance for the discussion in this paper. For this reason, and because it may be the more encompassing term, well-being is the term used in this paper.

A large number of empirical econometric tests confirm the importance of technological change and resulting productivity increases for growth and development. We observe, for example, steady energy efficiency improvements over an extended period in most OECD countries. Thus, we include the level of technology, TL, in our model. Our analytical framework for explaining longer-term development of well-being can be summarized thus:

$$WB = f\left(RC, HC, NC, HSC, TL\right) \tag{1}$$

where:

WB = Well-being;
RC = Real or produced capital;
HC = Human capital;
NC = Natural capital which has two main elements, resources sold in markets—Market Natural Capital MNC, and Non-Market Natural Capital NMNC (clean air, biodiversity);
HSC = Health and Social capital;
TL = The level of technological knowledge.

In standard wealth accounting, National Wealth, NW equals the stocks of capital, thus the definitional equation:

$$NW = RC + HC + MNC + NMNC + HSC \tag{2}$$

and thus:

$$WB = f\left(NW, TL\right) \tag{3}$$

Development of well-being is a function of the stock of national wealth, NW, and the level of technology, TL.

In literature, weak sustainable development, WSD, is total real NW per capita not declining over time. Strong sustainable development, SSD, requires that none of the individual capital components, i.e. RC, HC, MNC, NMNC and HSC, are reduced below critical or irreversible levels. For further discussion of criteria for sustainable development, see for example Pearce and Atkinson [10] and Alfsen and Moe [11].

Whether economic development will be sustainable in the longer term may, in the final analysis, depend on technological developments, see Aghion and

Howitt [5], chapter 5, and Hamilton and Atkinson [12], chapter 8. We return to this issue in section 3.4 below.

The criteria for assessing sustainable development should then be that national wealth per capita in real terms and adjusted for productivity growth should be non-declining, and that none of the components in equation 2 above is reduced below critical or irreversible levels.

3. Measurement

The Stiglitz Commission ([2], recommendation 11, p.17) recommends:

> Sustainability assessment requires a well-defined dashboard of indicators. The distinctive feature of components of this dashboard should be that they are interpretable as variations of some underlying stocks. A monetary index of sustainability has its place in such a dashboard but, under the current state of the art, it should remain focused on economic aspects of sustainability.

We now have fairly well developed methods for such monetary indexes, i.e. measurement methods for economic wealth, EW, cfr. section 3.1 below.

3.1. Monetary Indexes of Economic Wealth (EW)

Norway has been a resource-producing country for a long time, and wealth accounting goes back to the 1980s. Present methods used and presented regularly in order to inform policy are presented below.

Calculating Economic Wealth goes through three steps.

3.1.1. STEP 1: Calculating Resource Rents

The first step, based on an approach by Eurostat [13] and the United Nations et. al. [14], is to calculate the resource rents from market based natural resources, MBNC.

Resource rent = (4)
Value of production
± Product specific taxes/subsidies
- Raw materials
- Wage payments and capital costs
± Not sector specific taxes/subsidies

3.1.2. STEP 2: Decomposing Net National Income (NNI)

The next step is to decompose the observed net national income, NNI, on returns from the various types of capital.

NNI = (5)
Resource rents from non-renewable natural resources (oil and gas, etc.)
+ Resource rents from renewable resources (fish, agriculture, forestry, etc.)
+ Return on real capital calculated as an average rate of return on the total capital stock
+ Net income from financial wealth
± A residual containing return on human (and social) capital as well as income from natural capital not captured in the resource rent calculations

3.1.3. STEP 3: Converting Streams Into Wealth

The third step is to convert future income streams of income into (stocks of) Economic Wealth (EW):

Economic Wealth (EW) = (6)
Present value of future resource rents of non-renewable resources
+ Present value of future resource rents from renewable resources
+Real capital stock
+Present value from future returns on human capital
+Net foreign assets

For further details and concrete calculations of EW in Norway, see Alfsen and Moe ([11], pp. 14–17).

Figure 1 shows development over time of the renewable natural capital of Norway.

Note that "agriculture" has a negative value. This follows from the definition of resource rents, and the extensive subsidizing of the sector, that is, all product specific subsidies should be treated as a cost of production. Note also that hydropower has had a significantly higher value for the last 8 years. This is most often explained by the liberalizing of the power sector in Norway. Finally, note that all in all the management of the renewable natural resources seems to be improving. A majority of the natural resources have a positive rent, and the negative rents in agriculture are becoming less prominent.

Figure 2 shows the development in the components of national wealth (NW) in Norway from 1985 to 2011.

Non-renewable resources consist of oil, natural gas and mining, however, mining is only a tiny fraction of the total value (close to zero on average). We further note that the value of the non-renewable resources has been declining since 2004. The rent has however been invested in a fund, The State Pension Fund—Global, which transforms revenue from non-renewable resources to financial capital abroad according to sustainability criteria elaborated on in section 4 below; note the yellow bar.

Dividing total national wealth by the population gives national wealth per capita, see Figure 3.

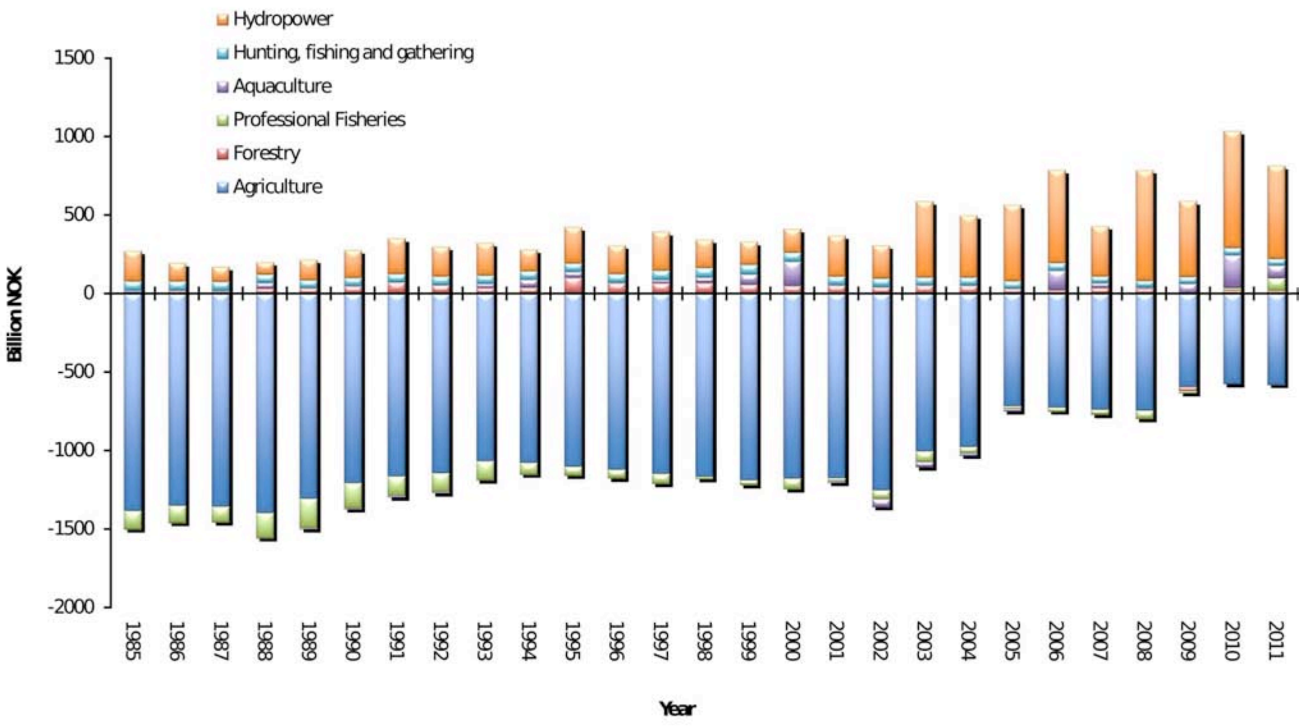

Figure 1. Development of renewable natural capital in Norway 1985–2011.

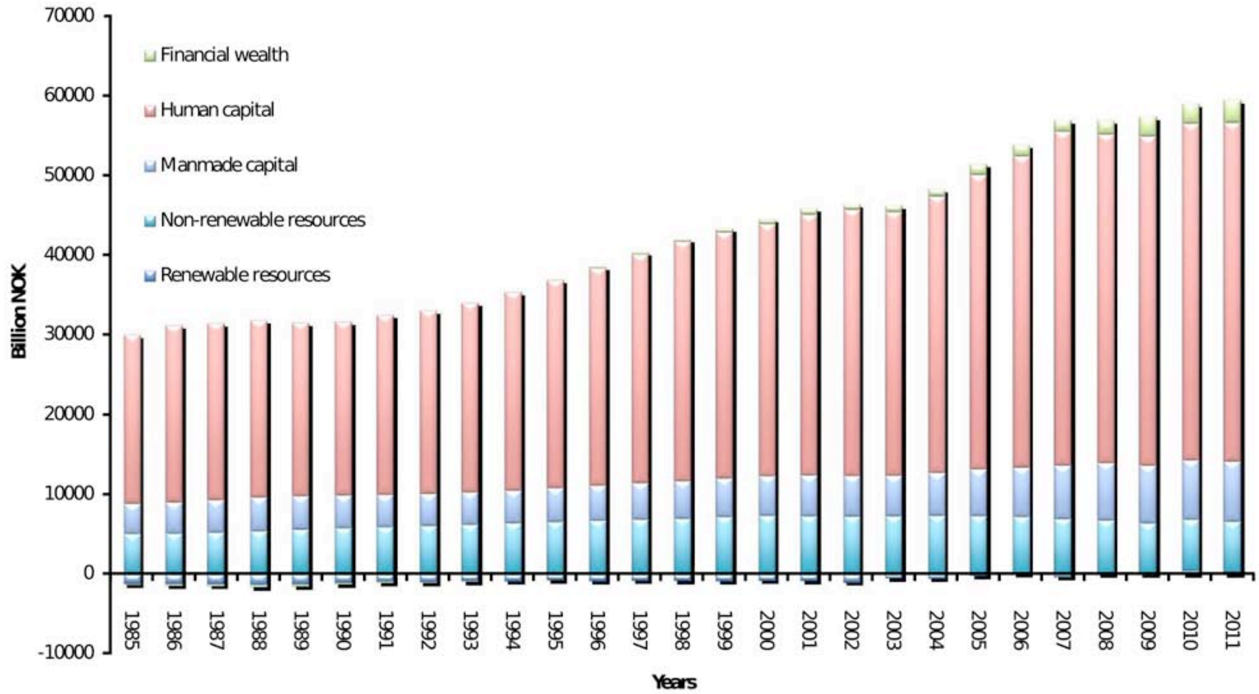

Figure 2. Decomposed national wealth (NW) in Norway 1985–2011

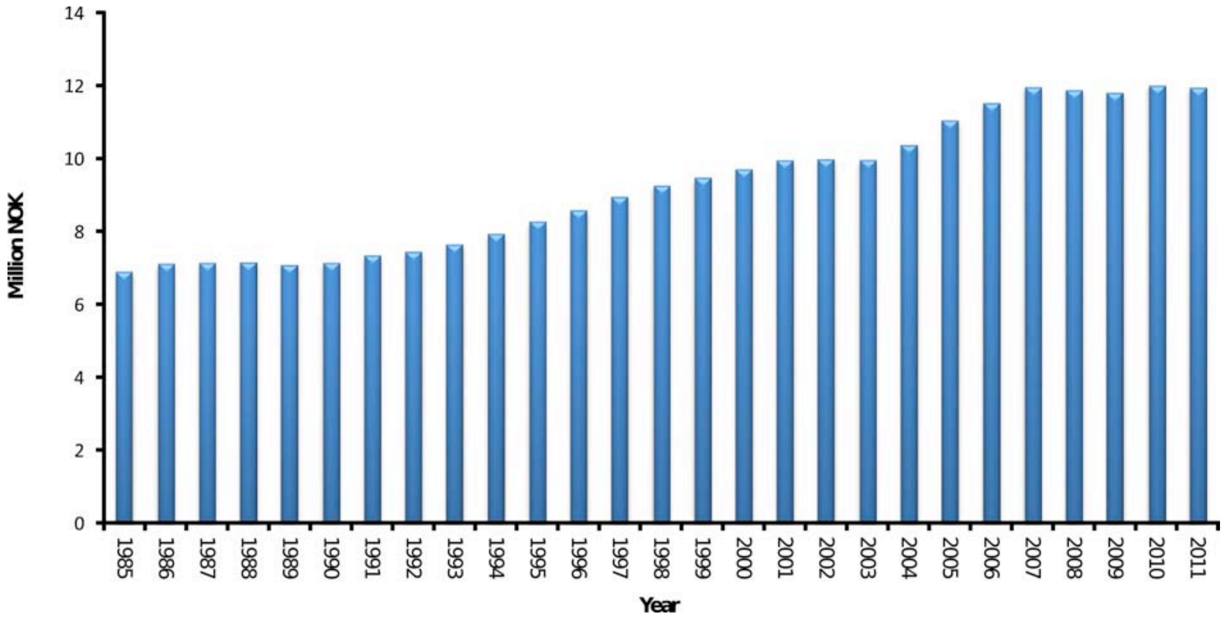

Figure 3. Development of national Economic Wealth per capita in Norway 1985–2011.

National wealth per capita has been increasing for most of the period, despite a large increase in population due to migration. Our measurements appear to be stabilizing at 12 million NOK per capita. In order to ensure sustainability, development must be followed closely. Human capital, the largest component of total economic wealth, was earlier arrived at as a residual, i.e. something that cannot be measured directly, however, in recent years great strides have been made in methods for direct calculations of human capital, and we now turn to this topic.

3.2. Direct Measurement of Human Capital

An improvement and further development of this established wealth accounting procedure is to estimate the stock of human capital directly using one of the following alternative methods, see Jorgensen and Fraumeini [15], Stroombergen et al. [16], Greaker [17] and Greaker and Lui [18]:

- The cost based method that measures human capital from the input side (how much is spent on education, etc.);
- The revenue generating method that estimates human capital from the output side (e.g. increased wages due to improved education and skills).

Recently the UNECE Conference of European Statisticians (CES) prepared a stock taking report providing an overview of what has been done in the field of human capital measurement [19].

The concept of human capital is broad, encompassing a range of personal attributes, such as people's health conditions. The OECD [20] has gradually extended its definition of human capital to:

> The knowledge, skills, competencies embodied in individuals that facilitate the creation of personal, social and economic well-being.

A pragmatic approach to estimate stocks of human capital in monetary terms focuses on economic returns, and implies that the health component of human capital will have to be dealt with separately from the education aspect.

The income-based approach measures human capital by looking at the stream of future earnings that human capital investment generates over the life time of a person. Hence, in contrast with the cost-based approach, which focuses on the input side, the income-based approach measures the stock of human capital by looking at the output side. However, outputs from human capital investment may be of many types (i.e. monetary and non-monetary, private and public), and the output measured by the life time approach is limited to the private monetary benefits that a person investing in human capital accrues.

Some developed countries now, more or less, regularly compute numbers for human capital stocks in monetary terms (although not as part of official statistics), and such calculations have been carried out in Norway for some time.

Figure 4 shows estimated returns to human capital in Norway compared to total wages paid.

3.3. Indicators in Physical Terms for the Non-Market Elements of Natural Capital

There are limits to the capital approach and the monetization of indexes of capital stocks. Thus, ecological approaches have their place in assessing what we have called non-market natural capital: they

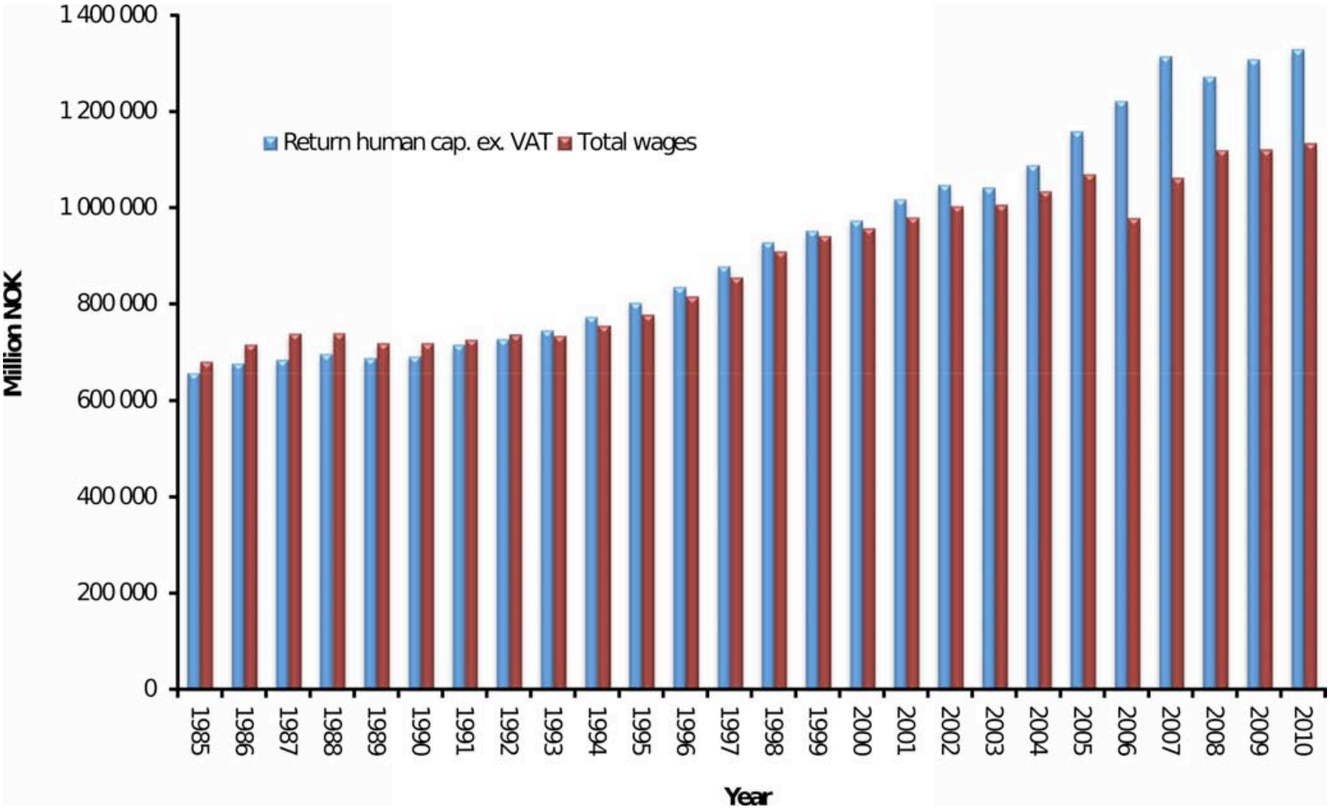

Figure 4. Estimated returns to human capital in Norway compared to total wages paid 1985–2011.

relate to the ability of the environment to sustain essential ecological resources and functions. See Pearce and Barbier [21], chapter 5. Recently Rockstrøm et al. [22] have proposed a framework based on planetary boundaries. These boundaries define the safe operating space for humanity with respect to the Earth system and are associated with the planet's biophysical subsystems or processes.

A main category in which critical assets are found is natural capital, as it is here where the assets that are essential for basic life reside. Although there remain scientific debates as to just which (largely non-market) assets are critical, and which are not, there is reasonable consensus that the following are very important, if not essential:

- A reasonably stable and predictable climate;
- Air that is safe to breathe;
- High-quality water in sufficient quantities;
- Areas of intact natural landscapes;
- A diversity of plant and animal life.

Some of the assets on this list may in fact be valued in monetary terms, although this is usually done in articles in research literature and more seldom in connection with wealth and sustainable development accounting. For example, it is difficult to put a reasonable monetary value on the stock of clean air, but we can put a value on the quantity of particulates in the air because we can value the associated health damages in the exposed population (and similarly for water pollutants, although here the question of exposure is more complicated). Intact natural landscapes can be valued in terms of the environmental services they provide to other assets and in terms of our willingness to pay to enjoy them (or simply to know that they exist)—not easy to value, but we know broadly how to do it. However, until such methods are refined and widely accepted, there remains the need for a few physical indicators. One should also account for the fact that some capital assets contribute to well-being outside the market place. While this is not a concern for produced capital, it may be for human, natural and social capital.

Non-market natural capital contributes to the well-being outside the market when people experience nature directly or when they derive pleasure from the knowledge that nature continues to exist in a reasonable condition. In principle, the well-being associated with the use of non-market natural capital may be valued in monetary terms. In practice, however, the scope for actually estimating such values in monetary terms is limited, and any such monetary indicator may underestimate welfare. As of now, some physical indicators are called for to assess the extent to which the non-market components of natural capital are, or are not, approaching critical or irreversible values.

3.4. Health Capital, Social Capital, Population and Technology

As mentioned in section 3.2, the health aspects of human capital are not included in the direct measures presented of stocks of human capital. An increase in life expectancy translates into improved health. More specifically, the value of health improvements may be defined as the value that people attach to the additional years of life that result from such improvements.

Arrow et al. [23] calculate the monetary value of an additional year of life by starting with estimating the value of a statistical life (VSL). A common method for estimating VSL is to study differential wages for jobs involving differential risks of a fatal on-the-job accident. For more details, see section 4.3.2 of their paper, but also comments by Hamilton [24].

If one thinks this is complicated, or if one finds it difficult to put monetary values on an extra year of life, one may simply use a physical indicator of the life expectancy at birth—which is readily available in many countries. This is done in the Norwegian SDI set.

Social conditions, governance and institutions are important factors for development. Whether such factors are critical for sustainable development is not clear, but indicators for such factors are needed. D'Ercole and Salvini [25] argue plausibly that social welfare systems are important. The World Bank [4], [26] in their estimates of Adjusted Net Saving refer to intangible capital as a residual. In the Norwegian core sustainable development indicator (SDI) set, one uses a physical indicator of the share of people of working age that are receiving non-working benefits (disability and long-term unemployment benefits) compared to the total population in the labour force – as the share is large and increasing it poses a challenge to the future labour supply and to government finances.

Population is a capital asset. It could seem intuitive that when population size changes the criterion for sustainable development should be non-declining comprehensive wealth per capita. Arrow et. al. [23] identify conditions under which this intuition actually holds true, and in their empirical calculations they simply adjust changes in wealth between two time periods (which they call comprehensive investment) for population growth in the same period.

As previously mentioned, Aghion and Howitt [5] explore the role of technology using endogenous growth models as an aid. Their general conclusion is that:

> The chances of achieving sustainable growth depend critically on maintaining a steady flow of technological innovations ([5], p. 151).

Hamilton and Atkinson [12], chapter 8, discuss the role of total productivity growth or future technological developments for sustainable development and present estimates for a number of countries. Their results depend heavily on whether technological improvements are assumed to be exogenous and costless or endogenous; this being of far greater importance in the first case.

According to Acemoglu et al.:

> While a large part of the discussion among climate scientists focuses on the effect of various policies on the alternative—and more "environmentally friendly"—energy sources, the response of technological change to environmental policy has until very recently been all but ignored by leading economic analyses of environmental policy, which has mostly focused on computable general equilibrium models with exogenous technology ([27], p. 1).

In their empirical work, Arrow et al. [23] follow the procedure of merely adding total factor productivity growth (TFP) to changes in total wealth between two periods—what they call comprehensive investment—and thus assume for practical purposes that technological change is costless and exogenous ("manna from heaven"). It makes a great deal of difference to their empirical results. For example, the US has negative comprehensive investment between two recent time periods if one does not add TFP growth.

For our part, we think one may risk making too optimistic estimates of sustainable development by simply adding TFP growth. Technological change involves investment in research and development (R&D). Expenditures on R&D are therefore a part of the change in total wealth between two time periods, and we would prefer to use empirical numbers for such expenditures to assess the role of technology in wealth accounting.

There is also a lack of empirical analyses of this key issue for sustainable development, and more research is needed.

4. Sustainable Development Indicators for Policymaking: An Example from Norway

For countries dependent on non-renewable natural capital, transforming natural capital into other forms of wealth is a path to sustainable development. Thus, we will briefly illustrate how this policy area in actual practice is coordinated in a small, open and resource-producing economy—and how SDIs are used in policy making in Norway÷as we believe this illustrates in concrete and practical terms the usefulness of the analytical framework and the measurements (SDIs) discussed earlier in this paper for actual longer-term development policies.

Earlier in this paper we argued that one needs:

- An analytical framework;
- Measures to assess the sustainability of development;
- Institutions to coordinate longer term policies.

Norway has been a petroleum producing country for forty years, and non-renewable resources (oil and gas) presently contribute some 25 per cent of GDP, around one third of total government revenues, and a large share of the surplus of Norway's balance of payments. It would be very misleading to use GDP per capita as a core SDI in Norway, as use of non-renewable resources, as underlined above, is not subtracted according to present national accounting standards. Norwegian GDP could increase rapidly while drawing down exhaustible resources. Thus wealth accounting, as illustrated in section 3.1 above, and monetized estimates of total or comprehensive wealth and produced capital, market-based natural capital and human capital are presented regularly. In addition Norway has established a national SDI set within a capital framework which also contains some physical indicators of critical natural resources—a Nature Index. An index of life expectancy at birth is used as a proxy for health capital.

Employment is high and unemployment is low in Norway, but a large share of the population of working age is receiving non-working benefits (disability – and sickness benefits), and this is seen as a challenge to longer term sustainability, both as a social issue and because a smaller labour force has to support a rapidly ageing population. Thus, as mentioned above, the number of people on non-working benefits as a share of the working population is used to monitor these aspects. Longer-term fiscal sustainability is also seen as a challenge to sustainability. Therefore, employing generational accounting methods, one may use the deficit as a percentage of GDP in 2060 (under certain assumptions) as an SDI of such conditions.

The Ministry of Finance is the institution responsible for economic and fiscal policies, and is also responsible for coordinating policies to enhance sustainable development. Under this ministry, a saving instrument for the revenues from non-renewable resources (oil and gas), a Sovereign Wealth Fund (SWF) – today named The Government Pension Fund – Global was established in 1990. All revenues from petroleum are placed directly into this fund. In 2001 a savings rule – a fiscal guideline – for domestic use of petroleum revenue was adopted by Parliament.

The Hartwick rule [28,29] provides a simple rule of thumb for sustainable development in countries that depend on non-renewable natural resources. The Hartwick rule holds that consumption can be maintained if the rents from non-renewable resources are continually invested rather than used for current consumption.

The Norwegian fiscal guideline is akin to this rule. Only the rate of return of the stock of financial capital in the Norwegian SWF, which now stands at some 660 billion USD, is to be used domestically for current consumption through the central Government Fiscal Budget. Thus, stocks of Norwegian non-renewable natural resources are transformed into other forms of wealth—a basic rule for sustainable development policies. For more details, see Moe [30,31], The Norwegian National Budget 2013 [32]—the government's main yearly White Paper on economic policies —which contain chapters on both sustainable development and climate change, and the recent Long Term Perspectives for the Norwegian Economy [33].

An important aspect is global sustainability and Norway's contribution to this. To assess this further with regard to climate change, one could use the product of an assumed social cost of carbon multiplied by the amount of CO_2 emitted by Norway as an indicator.

5. Conclusions

Important elements of sustainable development, like the challenge of climate change, are global problems. Thus, ideally one should have global agreements, indicators, institutions and policies. As of today however, and for the medium term, current policies to sustain present well-being for future generations will probably be largely national with relatively little regional or global cooperation and coordination. Thus, one needs an analytical framework for such policies, national indicators to monitor developments, criteria for assessing sustainability, and national institutions to carry out these tasks.

Each country concerned with policies to enhance sustainable development must chose the framework and set of national indicators best suited for their situation and prospects. We have argued in this paper —based on recent economic literature and Norwegian experiences—that developed countries with established institutions and statistical bases, would benefit from a core national set of SDIs consisting of:

1. Monetary estimates of National or Comprehensive Wealth in real and nominal terms, adjusted for population and technological improvements between periods.
2. Monetary estimates in real terms of real, produced capital (RC), human capital (HC), health capital (one could for simplicity—as is the practice in Norway—simply use estimates of life expectancy) and the market based natural capital base (MNC). Such measures are necessary, but not sufficient, to assess strong sustainability. That is because they do not convey the very real limits to substitutability, impending thresholds for natural capital, or possible irreversibilities and catastrophic events. Thus, indicators are required to assess such conditions and how they develop over time, cf. 3 below.
3. Some indicators in physical terms for the most important or critical elements of non-market natural capital (NMNC)—e.g. climate change, biodiversity based on an ecological approach.
4. Physical indicators of social capital (conditions) and the functioning of institutions—as appropriate

to the developed country in question.

Even if SDIs under 1 and 2 above increase in real terms per capita, as they presently do in Norway, indicating weak sustainability, we argue that it is also necessary to monitor SDIs under 3—especially critical non-market natural resources—and 4 to see if what we have called non-market capital are on sustainable development paths or not.

For all countries, and especially resource-producing ones, one should compute annual estimates of Adjusted Net Savings (ANS)—as published by The World Bank as a simple macro indicator and check on sustainability. Their estimates published in The Changing Wealth of Nations in 2011 [4] and annually in their World Development Indicators, show negative adjusted net savings for a number of developing countries—especially resource-producing countries in Africa—which is an indication of non-sustainable development paths. Especially for resource-producing developing countries, it would be useful to compute ANS regularly, possibly each year in addition to GDP, to get an annual check on whether the country in question is on a sustainable path. In any case, there is logic for extractive economies such as Norway in using a "depletion-adjusted" measure of net saving, such as ANS. The new SEEA central framework [34] suggests this as an aggregate sustainability indicator.

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Editorial

Sustainability Science: Progress Made and Directions Forward

Barry Ness

Lund University Centre for Sustainability Studies (LUCSUS), P.O. Box 170, SE-221 00 Lund, Sweden;
E-Mail: barry.ness@lucsus.lu.se; Tel.: +46 462224809

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I am honored to contribute an editorial for the inaugural issue of Challenges in Sustainability (CiS). It has provided the opportunity for me to take a step back and reflect on both the developmental progress in the field of sustainability science since its formal launch, now over twelve years ago [1,2], and where the field might head in coming years. While it may always feel that the field is changing too slowly to keep up with the challenges it addresses, the developments have been noteworthy, especially in academia. I will discuss three areas: education, research and institutional development.

The growing offering of sustainability (science) educational programs at all levels has been an important part of the field's evolution. Individual areas of concentration can include business and management, leadership, engineering, or policy management, to name a few. Flagship programs are now found throughout the world, including Arizona State University, Leuphana University of Lüneburg, and the University of Tokyo. In addition, programs at smaller academic institutions such as Furman and Kean Universities in the U.S. have arisen to meet the increasing demand for sustainability education. In Sweden, where I am based, there are international master's programs in sustainability at Uppsala, Stockholm, Malmö, and Lund Universities, as well as Blekinge Institute of Technology. These programs and their different foci, seek not only to increase student knowledge to understand the complexities of sustainability challenges, but also aim to strengthen key competency development [3] in areas such as facilitation and strategic leadership.

In addition to sustainability education, the nature of research projects and programs in the field has also changed. The changes have been driven by both top-down funding priorities to finance research that is more relevant to society, and bottom-up desire from scholars to carry out more integrated work. This has led to the slow evolution from a focus on descriptive-analytical research, with emphases on understanding the effects of environmental change, to transitional (or transformational) research agendas that embrace working in closer collaboration with societal stakeholders. Such research may concentrate on, for example, envisioning and scenario exercises, or problem-solving strategies beyond change strict policy change [4,5]. Transitional sustainability science research is being carried out by individuals in innovative Ph.D. projects focused on single case studies using particular theories and approaches, and by networks of researchers in longer-term programs, such as the Earth System Governance project (www.earthsystemgovernance.org), united by common sustainable development themes.

To operationalize the education and research agendas in sustainability science, new organizational constellations have developed. Changes have ranged from the creation of new faculty structures at a number of universities, to the establishment of interdisciplinary research schools and programs. The Lund University Centre of Excellence for Integration of Social and Natural Dimensions of Sustainability (www.lucid.lu.se) is just one example of a longer-term program that unites senior and junior staff and Ph.D. candidates from disciplinary backgrounds including

Economics and Economic History, Philosophy, Physical Geography, Human Geography, Political Science, and Human Ecology. The frequent interactions via discussions, debates, and joint publications have the goal of, amongst others, fostering new professionals who are capable of and accept working with the theoretical and empirical multiplicities [6] often inherent in sustainability education and research.

Despite the advancements over the past decade, there is still much to be done. Continued creativity in restructuring academic disciplines, departments, and funding and tenure incentives are necessary to promote the interaction needed to achieve the interdisciplinary goals of sustainability science. Sustainability issues must also be strengthened in other areas such as the arts and humanities utilizing alternative forms of knowledge dissemination. In the area of education, additional sustainability programs are still needed, but more importantly, there must also be increased efforts in mainstreaming sustainability into all educational programs at different levels. Finally, the field must also continue to place strong emphases on reaching outside of academia in addressing pressing societal challenges.

The launch of Challenges in Sustainability represents an important step in further strengthening the field. The journal's broad aims that focus on systemic analyses of sustainability challenges, solutions and transition processes, and associated trade-offs within socio-ecological systems, will create an important publishing outlet for scholars involved in integrative research. Furthermore, because Challenges in Sustainability is open access, it will mean that the knowledge produced in it can reach a wider range of stakeholders, adding one more attribute in a sustainability science we want to create.

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Challenges in Sustainability

Research Article

The Pitfalls of Sustainability Policies: Insights into Plural Sustainabilities

François Mancebo

International Research Center on Sustainability, Reims University, 57 bis, rue Pierre Taittinger, 51096 Reims Cedex, France; E-Mail: francois.mancebo@univ-reims.fr; Tel.: +33 612537446

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Abstract: A lot can be learned from the numerous pitfalls of sustainable development implementation: they outline how collective representation, short term interests and balance of power can undermine sustainability. For instance, the usefulness of global institutions in dealing with sustainable development is questionable as most are skewed toward the interests and perceptions of developed countries. The notion of sustainable development itself induces a profound cleavage between academic authors and the actors of its implementation, some of whom confuse it with sustainable growth (which favors spatial equity), whilst the others with environment management (which favors intergenerational equity). This polarization is a real problem, since originally, "Our Common Future" report promotes an inclusive approach, able to cope with both equities simultaneously. Finally, if there are obligations toward future generations, there are also obligations toward the current generation. The key issue for effective sustainability policies should be making them acceptable to everyone by including the expectations of local societies and communities. As a matter of consequence, universal solutions do not exist. They would not meet the specificities of local circumstances. The traditional prescriptive sustainable development model should give way to flexible plural sustainabilities. Singular, top-down, global-to-local approaches to sustainable development should be substituted for multiple sustainabilities.

Keywords: actors strategies; environmental policies; planning; sustainability

1. Introduction

Throughout the 1990s, starting with the release of the World Commission on Environment and Development report [1], and even more so following the Rio Summit, sustainable development began being widely discussed among international organizations such as the OECD, the European Union, and the WTO, as well as various NGOs. Rio's Agenda 21 has seen national and even regional and local governments enter into

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discussions on sustainability [2]. But with the ever increasing debates on sustainable development, the term took on a multiplicity of sometimes contradictory meanings [3]. It became an all-purpose grab bag of notions such as "development that is tolerable to ecosystems", "development that spares natural resources", "development that is conducive to a good quality of life", "that permits economic growth", "that drives employment opportunities", "that encourages social cohesion", and so forth. The situation is now so complex that it needs mapping [4]. This is all but natural as it is impossible to answer the basic question of what is sustainable and what is not because sustainable development is not only about science, but also about values [5], which means that various views and interpretations are likely to thrive since values may differ considerably between cultures and over time [6].

However, the core idea of sustainable development is simple enough: recognizing the finite nature of our biophysical environment. It promotes a type of development that meets the current needs of our societies without compromising those of future generations. Such a definition, however, points out three difficulties which are developed in this paper:

- The assumption that large and small scales of action can be treated similarly is all but evident (for example the nesting of local agenda 21s within Agenda 21). Some environmental constraints that can seem absolute at the global level, often perceived as a matter of survival, appear merely insignificant at local or regional levels.
- Frequently sustainable development is confused with sustainable growth which, moreover, can be considered an oxymoron. The result is a contradiction between the imperative of a slowdown in the use of resources on the one hand and the willingness to ensure steady economic growth on the other. All the more so, since this contradiction creates an ever-larger gap between rich countries, which favor the environment and intergenerational equity, and poor countries, which favor economic growth for the sake of spatial equity.
- According to the "Our common future" report, if there are obligations toward future generations, there are also obligations toward current generations. All the more so, since predicting what kind of resources these future generations will require is a matter of speculation.

Besides, these three difficulties outline how collective representations, perceptions, short term interests and the balance of power between public actors may undermine the success of sustainable development policies—I shall call them sustainability policies—promoted by local societies and communities.

In this article, I will use the term sustainability as a synonym for sustainable development. Some authors consider sustainability to refer to objectives to be achieved, with sustainable development referring to the processes to achieve them [7]. Others interpret sustainable development as focusing on ameliorating economic growth by taking into account the environment, while sustainability focuses on the ability of humanity to live within the environmental limits of the planet [8]. Strictly speaking the distinction between sustainability and sustainable development is logical, otherwise the word development would be entirely useless, but at the same time it "needlessly complicates the sustainable development debate and merely shifts the complex and vibrant interpretational debate to the conceptual level" [9]. I agree with this idea since the debate on the difference between sustainable development and sustainability remains unresolved [10]. Leaving this issue open may create a "constructive ambiguity" [3].

2. Linking the Different Spatial and Temporal Scales: A New Catch-22

One major issue when trying to implement sustainability is the relevant scope to effective policies [11]. This issue becomes a bottleneck when considering, for example, cross-border pollution [12]. Cross-border pollution is classically connected with global phenomena such as greenhouse gases, or gases that impact the stratospheric ozone layer. However, it is a widespread problem with sources which can be precisely located. I will mention here three very different cases. In 2005, the explosion of a chemical plant in north-east China spilled huge amounts of benzene—a carcinogenic substance—into the Songhua River, which provides drinking water to millions of people in China and Russia [13]. Russian cities downstream had to cut their water supplies, affecting millions of people for several weeks. This ended in a long legal dispute between Russia and China over responsibilities and compensation [14]. This contamination can also be chronic: Japan is under constant threat from acid rain caused by the sulfur injected in the atmosphere by China's Shanxi province industrial plants and carried across the Sea of Japan by the wind [15]. In particularly great danger are the famous ice trees (juhyo) along with the fragile ecosystem that supports them on Mount Zao [16]. Sometimes cross-borders pollution ends in everlasting conflicts without solution. So is the contamination of the Rhine river by the French mining company Société des Mines de Potasse d'Alsace (MDPA), which resulted in a long-running environmental dispute [17]. The Netherlands accused the French company of dumping salt effluents (sulfates, ammonia, chlorides) into the Rhine. This pollution made the Rhine water unfit for agricultural purposes in addition to corroding water delivery systems. Despite a 1989 order by the Strasbourg Administrative Court in favor of the Dutch government, things continued largely unchanged until the MDPA site was closed by injunction of the court in 2004 [18].

The three cases show how difficult it is to delimit relevant areas for sustainability policies—the functional space of an industrial site, including its employment base, does not usually coincide with the area affected by the atmospheric or hydrographic pollution that it generates, and it often does not coincide with the territorial jurisdiction of the institution charged with regulating such issues, notwithstanding all the discussion about linking scales of action. Indeed, the assumption that large and small spatial scales can be easily drawn up raises a number of questions. Can the principles of sustainability [19,20] really be applied identically from the global down to the local level, as if each level were controlling the other in some sort of gigantic planetary mechanism?

It is true that some global issues like climate change or ozone depletion need global answers embodied by top-down policies which should be translated directly into regional policies [21]. Johan Rockström identified a set of such critical sustainability issues where perturbations resulting from human activities present a risk of unacceptable global environmental change [22]. But even in these cases, if the top-down initiatives prove unenforceable because they have not been adjusted to accommodate local or regional considerations, they will be useless in addressing these problems, as with the mechanisms to reduce carbon emissions from deforestation and forest degradation (REDD) [23].

Thus, it would be an error to apply policies locally that do not fit the concerned areas, as would it be to dictate a single approach in defining problems and drafting solutions. In France, the utilization of sewage sludge on agricultural fields illustrates how not taking local concerns into account—here, perceptions of sewage sludge as a nuisance—can lead to major problems. While working on the periurbanization dynamic in the Ile-de-France (Paris metropolitan region), I realized that land application of sewage sludge often resulted in significant neighborhood conflicts addressing the quality of life at the local scale when this practice was considered sustainable at the regional scale [24]. These conflicts combined with distrust in industrial agriculture after the BSE (Bovine Spongiform Encephalopathy) crisis in the 1990s to provoke a persistent and massive rejection by the population (either neighbors or customers) of the land application of sludge (appendix). As mentioned by Flor Avelino, attempting to change human perceptions and behavior through imposed technocratic approaches usually leads to unsustainable power relations and conflicts [25]. However, it is important to remember that for more than a century Parisian sewage sludge was used to grow vegetables for the capital, and that traditional family gardens have always put human manure to good use. If sewage sludge has no health risks, it certainly has others: the risk to a local representative or official committed to sewage sludge utilization of being sued; the risk to food industry actors of being hit by a boycott, more out of fear than due to an actual event; and, finally, the risk of scapegoating faced by a farmer who uses sludge on his fields in an environment where farming practices are often called into question.

The preceding cases highlight the difficulties involved in drawing up different scales of action; neither general, normative measures nor strictly local ones that undermine the scope of action can contribute to a solution. Such cases point to the explosion in Northern societies of a climate where opinion dictates its choices on a purely emotional or self-interested basis, a sort of generalized NIMBY or Not In My Backyard atmosphere, in which local residents are opposed to the roll out or extension of public goods such as industrial sites, waste disposal facilities, communication lines, refugee processing centers, etc. Firstly, NIMBY opposition gives concerned inhabitants a unified and coherent political grouping, clustered around so-called common interests—they form de facto actor coalitions [26]. But this type of action usually evolves quickly to take on different forms, which differ according to what their activists consider to be the key issue worth defending; the result is different pressure groups finally emerging and opposing each other. They have contradictory interests, which is all but normal when considering sustainability transition, which requires synergetic but also antagonistic power dynamics between moderate and radical groups of actors [25]. But instead of developing an inclusive approach by focusing effort on dialog between, and within, all these different groups, public authorities—be they local, regional or national—and project promoters more than often fuel the conflict between the different pressure groups by choosing only a few interlocutors among them whilst ignoring the others. Naturally, when this type of situation occurs, tension grows between the different pressure groups and the situation rapidly becomes chaotic, such that everything is finally disrupted—not just the project itself, but also daily life in the local communities where the project is intended to be put in place. Living conditions worsen rapidly for inhabitants, until a threshold of acceptability is crossed, whereupon public authorities and project promoters can impose just about any project, no matter how dubious, justifying it through exceptional circumstances (sometimes even claiming a state of emergency). Can such an attitude be considered a deliberate strategy on the part of the project stakeholders? To quote Maarten Hajer, "policies are not only designed to solve problems, problems also have to be designed to be able to create policies"

[27]. Pressure groups usually oppose each other because the narratives that they develop about their environment, and specifically about "quality of life" and "good environment", are different. They oppose each other on the basis of "essentially fragmented and contradictory statements", to quote Hajer again [27]. Thus, environmental conflict occurs primarily over the interpretation of so-called environmental problems. As the different pressure groups realize that they need one another to craft effective political agreements, these conflicts should normally give way to the formulation of a common narrative and objectives [28]. But social power relations have a delicate balance and need time to grow their sources of trust and legitimacy. This evolution never happens when the stakeholders (mainly local authorities and project promoters) act in such a way as to block the process at its conflictual phase.

At this point, the difficulties in drawing up the scales of action as well as the resulting problems, for instance NIMBY movements, highlight the importance of taking imported sustainability into account as an essential component for sustainability policies. David Pearce speaks of imported sustainability when an area guarantees its sustainability by transferring its cost onto other areas; for example by exporting pollution or waste, exporting activities that pollute, or by purchasing natural resources at artificially low prices [29]. This area meets the needs of its population while appearing, on the face of it, to meet the general criteria of sustainability. Internal sustainability is thus achieved through the export of undesired products or impacts, to the detriment of the area's external sustainability [30]. Thus, policies aiming at the realization of sustainable development must be conceived on areas large enough to minimize imported sustainability from outside areas [2,22].

Though less apparent, difficulties also concern temporal scales. Just as inequalities and injustices may arise from one area to another, from one community to another within the same area and from one person to another within the same community, they can be handed down to from one generation to the next. For instance, it seems easy to differentiate between renewable and non-renewable resources, based on man's and society's interactions, destructive or not, with the environmental resources that are accessible to him. However, there is a certain gray area, in that, generally speaking, a renewable resource is a resource that is utilized less rapidly than its natural capacity for regeneration or regrowth. But how are we to estimate this capacity? In many cases, the rate of renewability of a resource is difficult to determine. Forest resources are a good example, with renewability estimates varying greatly depending on whether one is concerned primarily with biodiversity, lumber production, landscape dynamics or soil quality [30]. Furthermore, the notion of "non-renewability" falsely suggests an irreversible process. Irreversibility thus applies only to the scale of human history or that of future generations. It should also be noted that man can produce "non-renewable" resources, for example soils that can take thousands of years to form when left to nature [32].

3. Resources, Growth and Development: Delicate Balances and Complex Trade-Offs

Our actions take place within a vast system of bio-physical networks. These actions generate a specific discourse, produced by social practices and productive of social practices. This can be considered a "specific ensemble of ideas, concepts, and categorizations that are produced, reproduced, and transformed in a particular set of practices and through which meaning is given to physical and social realities" [27]. In this sense, this discourse structures the environment, or the "nature", of a society. These are both social constructs and, as such, are often exploited by different policy-makers in an attempt to create their own definition of the real world to cover incomplete arguments and biases [33]. So, the environment is embedded in societies. The human being builds a representation of the ecosystems he lives in, and calls it "the environment", he makes of its resources taking (air, water, minerals), inputting (pollution) and altering (housing, transport) [17]. The environment more-or-less represents a noisy neighborhood to which we must adapt. Depending on the moment in a societies' history, not all the "items" present in ecosystems are necessarily considered resources. The knowledge we have of our environment changes continually: nature in medieval times was not the same as it is today, if only because the dynamics of the atmosphere and genetics were not well understood. This, of course, raises the crucial issue for sustainable development: what is a resource?

A resource cannot be considered as such by its mere presence. Societies must also possess the knowledge required to make use of it. Coal for example only acquired value as a resource once its combustible properties were discovered and techniques for its use were developed. Prior to this, coal had only negligible value. In addition, inventories of resources change over time. New practices or new relationships to the environment give rise to new resources while others disappear or move toward obsolescence. Besides, expressions such as "repairing nature", "restoring nature", "remediating nature" or even "recreating nature", are very ambiguous. Thus, when some of Spain's political ecologists—for example the Ecologistas en Acción de Tierras de Granadilla [34]—speak of "restoring" Mediterranean nature, to which Mediterranean nature are they referring? The climacic deciduous forest that covered Spain ten thousand years ago? The sparse open forest of green oaks, cork-oaks and carob trees of antiquity? Or the garrigas (scrublands) of recent centuries, which in fact represent an advanced stage of forest degradation from an ecosystemic point of view? In fact, it is usually the garrigas [35,36]. This is not illogical, if we consider that nature is essentially a social construct and there is nothing like a unique ideal biophysical type. But precisely because it is a social construct, the garrigas that the Ecologistas en Acción value so much tell us a lot about their cultural and historical references as well as their vision of Spain today. Garrigas are the recent past of the country so there is nostalgia in such a choice, besides, garrigas are associated in the Spanish collective memory with the civil war—Bunuel's movies and media coverage of the war show scrublands— and the bull silhouette of the Spanish brandy Osborne dominating arid landscapes [37,38]. The point is this: were the promoters or the garrigas option conscious of the history they valued indirectly? Probably not.

Besides, what sense does it make to conserve resources for future generations, when we cannot know which resources they will require? Firstly, when asking this question, which generations are we considering? One could argue that everybody thinks spontaneously of his "own" future generations—i.e. those closest to him, both socially and culturally—and not about humanity in its entirety, which remains a rather vague reference. Similarly, at what time horizon does one cease to be interested in the future? On this issue, there is likely a wide divergence of opinion amongst people in different regions of the world; the future is not perceived in the same way when life expectancy is thirty-five as when it is eighty-five, when basic food and health needs are met and when they are not. In addition to the bizarre idea of putting ourselves in the place of future generations to decide on their best interest, sustainable development glosses over the fact that human history, rather than being a continuous process, alternates between relatively stable periods and sudden ruptures that are favorable to development and that cannot be foreseen. Considering that resources vary over time, is our concern for future generations a good enough guide for adapting our productive activities so as to make them less harmful to the environment?

More importantly, the aporia created by trying to determine which resources will be required by absent third parties in an uncertain future results in a theoretical bottleneck when designing sustainability policies. It leads to two definitely divergent views on sustainability—one "weak", and one "strong" [39]. Proponents of "weak" sustainability consider manufactured capital capable of being completely replacing natural capital, with technology answering the environmental challenges arising from the production of goods and services: "the world can, in effect, get along without natural resources, so exhaustion is just an event, not a catastrophe" [40]. Proponents of "strong" sustainability denounce this point of view. They consider manufactured capital incapable of perfectly replacing natural capital, especially some global processes vital to human existence such as the climate or the ozone layer [41,42]. In this perspective, it is crucial to limit the qualitative and quantitative degradation of natural capital by diminishing the quantities of material and energy that are extracted from the biosphere and altered [43]. All the more, since there are critical thresholds at which tiny perturbations may irreversibly transform the state of the Earth system once what Lenton calls "tipping elements" cross them. As far as climate change is concerned, monsoon systems, jet streams, coral mega-reefs, tropical rainforests maybe considered "tipping elements" [44].

The Brundtland report is no help in determining the relation between these two sustainabilities. Of course, it points out that the satisfaction of human aspirations should "not endanger the natural systems that support life on Earth: the atmosphere, the waters, the soils, and the living beings… It is part of our moral obligation to other living beings and future generations" [1]. But, simultaneously it promotes a more rapid economic growth in order to overcome poverty, in reference to the "trickle-down theory" which affirms that economic growth is eventually of benefit to everybody and as such reduces poverty [45]. Such a position is ambiguous. It creates confusion on what the substance of sustainable development is, giving room to the divergence between "weak" and "strong" sustainability. Indeed according to Herman Daly, current sustainable development policies seek to correct a mode of development often confused with a mode of growth. As such, the term is oxymoronic as traditional economic growth is clearly unsustainable since it needs more and more resources and produces more and more waste and pollution [46]. Of course, these last years, there have been strenuous attempts to decouple economic growth from material consumption and, for example, to foster recycling channels for material resources [47]. But still, such an approach can be considered based on "weak" sustainability which, according to Rees, turns out to be a "morally bankrupt solution" to poverty [48]. This is not surprising, given that growth has been the mantra of western societies since WWII, stemming from the simplistic vision that increased production by means of industrialization automatically increases mankind's wellbeing. This was true for post-war Europe's devastated economies, at a time when 20th century industrialization was at its peak. It is no longer true in the 21st century, nor for the rest of the world. Yet this belief persists and has taken on a parasitic role in all reflections on sustainability. The Maastricht Treaty goes so far as to use the term "sustainable growth" as a synonym for "sustainable development" [49], so does a recent report from the OECD which drew together green growth and sustainable development policies [50].

Sustainable development can also be considered an oxymoron in that the term "sustainable development" itself conceals a fundamental contradiction. Etymologically, the word development implies structural change, be it in embryo development, the process of converting land to a new purpose, the qualitative changes of economic development, or more generally the transition to a new stage in a new situation. But sustainable means the exact opposite—among the many synonyms of the verb "to sustain", we find "to bear", "to continue", "to maintain", "to preserve", "to perpetuate". As such, sustainable development could be understood as "sustained change"—a change that can last forever—which would make it meaningless [51]. Of course, this oxymoron is purely semantic. But it introduces an apparent and original flaw in sustainable development. It induces a recurring question that features prominently in large sectors of academic works on sustainable development, namely, since the words "development" and "sustainable" are so opposed, what is the respective weight of each in the complex notion of sustainable development?

Historically, according to Waas, "in addition to its environmental roots the concept draws on the experience of several decades of development efforts" [9]. Indeed, some authors consider sustainable development to be the successor of traditional development, to which an important environmental dimension was added in 1987, with the WCED report [52]. Thus, human needs, quality of life and increases in everyone's capabilities and wellbeing are the principal issues of sustainable development [53]: As mentioned in Our Common Future: "Poverty...is an evil in itself" [1]. Finally, since sustainable development is a social construct, what it means depends entirely on how the people who define it—whoever they are—see the world they want to live in [6,54]. They make choices based on the values they decide to maintain or, more precisely, to sustain. Recently, Bill Hopwood drew up a system of classification and mapping of different trends of people's thought on sustainable development (status quo, reform, transformation) linked to their political and policy frameworks and to their attitudes toward change [4]. But all these trends have a point in common: when under-development threatens the environment and human needs, more development is required; but when development becomes an equal threat, more of the same kind of development is not desired [3].

4. Combining Spatial and Intergenerational Equity: From Sustainability to Place-Based Sustainabilities

In a general sense and in the first place, sustainable development is concerned with quality of life, which is about the place of every person in a complex society, about lifestyles and social ties, and not just with material consumption. As such, it seeks to promote a conscious co-evolution between human societies and the ecosystems within which they are embedded. For this reason, sustainable development should be considered a process and not an end state [55]; a process which considers the question of "how decisions are made": It is "not about mobilising resources to realise a pre-determined societal order. Rather, it is about adjusting the structures that regulate societal interactions so that they can encourage positive developmental adaptation" [56]. Therefore, the issue of determining what form of governance is the most effective for actions of sustainable development, is at the heart of sustainability policies. Despite extensive literature on governance for sustainability, "many of its fundamental elements remain unclear in both theory and practice" [57]. Indeed, the term governance, in itself, has very different meanings [58,59]. As far as sustainable development is concerned, and in a very general sense, governance is not only about the design and implementation of government policies, but also about the collective process of debate and decision through democratic interactions to ensure that these policies proceed along a sustainable path. It means that the effectiveness of sustainability policies is largely dependent on their acceptability and collective suitability [60]. Thus, the existing social and cultural fabric should not be forgotten [31]. It is, therefore, important to define, on the global scale, what a good environment is for the communities involved, i.e. one in which the improvement of environmental conditions stricto sensu (water quality, air, biodiversity, prudent use of resources, land and energy, etc.) leads to improved living conditions. To do so, it seems logical to put non-market institutions, local communities and individuals able to form self-determined user associations together as governance actors—alongside traditional public actors and organizations— to design sustainability policies. This is what Elinor Ostrom demonstrated earlier, when she proved, twenty years ago, that user communities can manage the commons more efficiently than the market or institutional structures, provided that these communities are legally empowered to exclude "free riders" [61,62].

Unfortunately, more than often, the organizations and traditional public actors of sustainable development are inclined to push aside this type of governance—complex and difficult to implement—to replace it with pseudo-governance practices proposing ready-made grids and rigid ready-made policies, in contempt of local realities. Such a bias is not confined to local authorities fostering their interests, nor to nations with rigid administrations. In fact there is a strong temptation on the part of international organizations to use normative control measures when dealing with global issues. These organizations produce a profusion of "good practices" furthering the interests of one actor or another. For instance, the World Bank directly supported sustainable development projects in poor countries by allocating funds that require the borrowing country to follow directives unilaterally issued by the World Bank [63]. But the priorities of the World Bank were very different from those of the populations. Of the six requirements imposed by the World Bank, two are quite revealing: "encouraging private business development" and "promoting reforms to create a stable macroeconomic environment, to facilitate investment and long-term planning" [64]. On the surface, the intention seems praiseworthy enough, considering that many requesting countries are plagued with widespread patronage. In the recent past, this approach has had many side effects: such requirements were not being suitably adapted to the local conditions and often resulted in disastrous, economic, social and environmental consequences [65]. One participant at a sustainable development conference summed it up thus: "A debate on standards is unavoidable. What sense do standards imposed by the North make, when they care more about micrograms of nitrates in water than about millions of salmonella germs" [66]. This pernicious effect fuels criticism that sustainable development reflects the unilateral insistence of elite Northern countries on concerns like global warming, population growth, species extinction and free market [67]. At the same time, it leads emerging and poor countries to give a veneer of sustainability to their actions, even when unrelated to their real objectives. Sustainability, thus, loses all credibility in the eyes of the local authorities, who write them off as mere whims of the rich nations. Once initiated into the game, they soon get busy maneuvering the imposed sustainable development objectives. Many countries who are unable to manage their resources sustainably will, for example, give much lip service to the themes of poverty and inequalities. They will try so as to legitimize policies which continue to destroy resources or ecosystems. Poverty may even become a resource when it allows access to funds aimed at restoring spatial equity. Obviously, there is need for a sound debate on the normative and practical tensions resulting from the juxtaposition of sustainable development and governance.

On the local scale, these rigid policies also tend to reduce sustainability to its technical dimensions, considering only biophysical, energetic, or ecosystem constraints, without considering any more the social side-effects [68]. For example, with the rising concern on climate change, "exemplary" buildings and devices —all technical solutions—are often favored to the detriment of more holistic approaches, such as active land management and transformation of the urban fabric (differential densification, restructuring urban cores, etc.). To promote "green" buildings, elected officials accept paying extra charges of up to 20% of the original costs to obtain a Low-Energy label. They are less interested in the urban design, which is more important to creating a real sustainable city but, of course, harder to implement and less profitable as an electoral issue, as in the Clichy-Batignolles urban project, in Paris [69]. Working within the IRCS (International Research Center on Sustainability) at Rheims University on an update of planning practice and theory with regard to sustainability and social justice, I realized that technical issues (such as resource conservation or reduction of greenhouse gases emissions) siphoned money away from other priorities and public and private actors' attention, in accordance with the earlier observations of Elizabeth Burton in similar situations [70]. Since the end of the 1990s, the European Union has financed climate and energy initiatives mainly when sustainability is addressed [71]. Prioritizing this climate topic in local and regional public policies—as in Climate Change Actions Plans—induces very localized eco-technical solutions: energetic autonomy of agglomerations with the development of local renewable energy sources, insulation of buildings, passive houses and so on [72,73]. But a zero energy housing development does not necessarily help in creating a sustainable neighborhood. A crucial issue is forgotten here: the fact that sustainable development is also about managing social change.

A larger and larger gap is growing between intergenerational equity (preservation of the resources and protection of the planet for the generations to come, which often goes with more technical approaches) and spatial equity (environmental justice, living conditions). These were not the original intentions of Our Common Future report, which features sustainable development in its ability to cope simultaneously with both spatial equity and intergenerational equity. When the United Nations assigned the writing of a report to the World Commission on Environment and Development (WCED), its mission statement mentioned explicitly that its objectives were how to reduce inequality and poverty without damaging the environment granted to the future generations [1]. Indeed, there is a general equity principle, which we could also call justice or fairness, at the heart of sustainable development [74]. In fact, there are many equities. It is possible to tailor the general principle by addressing different questions [75]. Academic authors usually differentiate between intergenerational equity, spatial equity—which includes intragenerational equity and geographical equity, procedural equity and, finally, interspecific equity [76]. But in fact, the dyad of intergenerational equity and spatial equity is the element that most strongly influences sustainability policies, especially by urging for a clearer distinction between short-term (spatial equity) and long-term (intergenerational equity). Spatial equity refers mainly to the short term and the right for present generations to meet their needs and aspirations, and to have a decent quality of life. It finally has a lot to do with the term "development" in "sustainable development" and with social justice. Intergenerational equity, on its side, refers mainly to the long term, to the right for future generations to live on a healthy planet which means to keep our economic activities within the environmental limits of the Earth. Fundamentally, it relates to the term "sustainable" in "sustainable development". Officially, of course, sustainable development is an integrative notion that should harmoniously unify development objectives with environmental objectives [77]. But, it is evident that these two equities are antagonistic notions, which cut across the antagonism between weak and strong sustainability seen above in this article: trade-offs are often necessary, which, currently, usually favor intergenerational equity, suggesting sacrifices among the general sustainability objectives. Besides, the environment is only one of the 3 "pillars" of sustainable development together with social and economic aspects. The idea of three separate and connecting pillars, leads to the erroneous impression that each one is, in part, independent of the others. But humanity is completely dependent on its environment, and the environment is completely transformed by the economy and the societies existing within it, and the resources used by the economy all come from the environment or the societies themselves, and so on [77]. Therefore the perception of the three "pillars" is certainly the least appropriate in depicting sustainable development; curiously it is the most popular [78].

5. Conclusions

There are numerous ongoing debates about sustainable development. Though the theoretical corpus on sustainable development is already considerable, it is constantly evolving and presents many internal contradictions. This is due, in large part, to its wide dissemination through various domains and sectors: political, administrative, activist, corporate, etc. As a consequence, different authors use the same words to describe sometimes very conflicting perspectives, goals and methods about how to foster transition to sustainability. They introduce their own cultural, scientific, political and ideological backgrounds into the debates. The success of sustainability policies is often compromised by poor coordination between different decision levels (states, regions, cities, local governments), each one with its own priorities and its own strategic position. In this paper, it has been shown that the well-known adage that sustainability should be "thought globally and acted locally" is very difficult to implement. Every person and community living has various relationships based on various territorial scales. Implementing sustainable development leads to permanent dilemmas, which generate radically different policies depending on the balance between equities.

So, there is no such thing as a single unified conception of sustainable development, and a key factor is explaining why it is so difficult to implement effective sustainability policies: around the world, existing political, cultural and economic contexts, as well as existing environmental policies, interfere with sustainability initiatives to create very complex situations [79]. Finally, since the multiple antagonistic views on sustainability cannot be reconciled, no single approach should be seen as correct. As a matter of consequence, there is no such thing as sustainability, there are only sustainabilities. Universal solutions do not exist and cannot meet the specificities of local contexts, anyway. Thus, traditional singular, top-down, global-to-local approaches to the sustainable development model should be substituted by multiple sustainabilities.

The hotchpotch of undifferentiated sustainability suddenly makes sense when you consider each initiative from a local perspective. Thus, local sustainability policies, rather than blindly observing global injunctions and rigid rules, should adapt themselves to local interests, local cultures and preceding codes or policies. Eventually, these local issues will often antagonize, as mentioned in this paper with cross-border pollution or imported sustainability conflicts. In reality, instead of focusing on objectives to be achieved, sustainability policies do make much more sense if considered as a process where different and even divergent views can be expressed and confronted. This position—an open one—acknowledges sustainable development as a political issue and gives insight into how to successfully foster transition to sustainability, it calls for a comprehensive approach that considers all human factors, such as collective representations, perceptions and power relationships.

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Appendix: Land Application of Sewage Sludge in France: Conflicts and Mistrust

In the 1970s, sewage sludge utilization in agriculture was a confidential and mutually beneficial arrangement between sewage treatment plants and farmers. Many authors stress the double advantage of transforming urban waste into an agricultural resource for nearby rural communities [80]. This practice gradually came to be organized under the auspices of the French Agency for Environment and Energy Management (ADEME) and the Permanent Assembly of the Chamber of Agriculture (APCA) as a sustainability policy initiative [81]. In 1986, the Council of Europe issued a directive to clarify the status of sewage sludge—one difficulty stemmed from its dual status as both waste and fertilizer—and the requirements for its utilization, as well as to provide health and environmental guidelines [82]. The French Ministry of the Environment transposed it into a national decree in 1988.

In the 1990s, sewage sludge production increased steadily as a result of both the incentive of the decree and stricter regulations on the treatment of waste water, sewage sludge use on agricultural lands increased sharply, giving rise to a high incidence of odor nuisances [83]. In the Paris regions, non-farmering neighbors began to protest: opposition movements appeared that antagonized local periurban communities [24]. Some land owners threatened to stop renting their properties for farming purposes, claiming that sewage sludge utilization would negatively impact their property value [84].

At the same time, certain sectors of the food industry, in particular food distributors, began taking positions to limit, or even forbid sewage sludge utilization. Indeed, at the beginning of the 1990s, the BSE (Bovine Spongiform Encephalopathy) crisis, in Europe also named the "mad cow" crisis, surged [86]. Linked to the incorporation of meat and bone meal in cattle feed, it lent itself to the idea that incorporating any non-traditional components into the food chain presents a health risk [87]. Confusion was such that there were even rumors that sewage sludge was utilized in animal feed, instead of animal meal from meat rendering facilities. Finally, the financial benefits of sewage sludge utilization, instead of constituting a positive argument, further increased distrust among the public, who perceive health matters and economic matters as systematically opposed [88].

Placed under considerable pressure, some farmers then began to refuse sewage sludge. In the Paris region, many authors addressed these conflicts between different local actors (farmers, non-farmers inhabitants, companies, local authorities, etc.) concerning the utilization of sewage sludge on fields, but no practical negociation tool to cope with this problem emerged [89].

Though, alternative disposal means for sewage sludge were rarely discussed by the opponents of agricultural utilization, who tended to frame the debate in simplistic "city vs. country" terms. These opponents, principally urban dwellers, tended not to see themselves as immediately concerned by the waste elimination problem. Sooner or later though they will have to come to terms with the fact that they generate the bulk of the waste and that if nothing is done they might one day "find themselves submerged in it" as expressed by an inhabitant of the village of Champlan, near Paris, during a study addressing the acceptability of this "nuisance" [89].

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Research Article

Sustainable Development within Planetary Boundaries: A Functional Revision of the Definition Based on the Thermodynamics of Complex Social-Ecological Systems

Bart Muys[1,2]

[1] Department of Earth and Environmental Sciences, University of Leuven, Celestijnenlaan 200E box 2411, 3001 Leuven, Belgium; E-Mail: bart.muys@ees.kuleuven.be; Tel.: +32 16329726; Fax: +32 16329760
[2] European Forest Institute, Mediterranean Regional Office, Sant Pau Historic Site, Santa Victoria Pavilion, St. Antoni M. Claret 167, 08025 Barcelona, Spain

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Abstract: The dominant paradigm of sustainable development (SD) where the environment is just the third pillar of SD has proven inadequate to keep humanity within the safe operational space determined by biophysical planetary boundaries. This implies the need for a revised definition compatible with a nested model of sustainable development, where humanity forms part of the overall social-ecological system, and that would allow more effective sustainable development goals and indicators. In this paper an alternative definition is proposed based on the thermodynamics of open systems applied to ecosystems and human systems. Both subsystems of the global social-ecological system show in common an increased capability of buffering against disturbances as a consequence of an internal increase of order. Sustainable development is considered an optimization exercise at different scales in time and space based on monitoring the change in the exergy content and exergy dissipation of these two subsystems of the social-ecological system. In common language it is the increase of human prosperity and well-being without loss of the structure and functioning of the ecosystem. This definition is functional as it allows the straightforward selection of quantitative indicators, discerning sustainable development from unsustainable development, unsustainable stagnation and sustainable retreat. The paper shows that the new definition is compatible with state of the art thinking on ecosystem services, the existence of regime shifts and societal transitions, and resilience. One of the largest challenges in applying the definition is our insufficient understanding of the change in ecosystem structure and function as an endpoint indicator of human action, and its effect on human prosperity and well-being. This implies the continued need to use midpoint indicators of human impact and related thresholds defining the safe operating space of the present generation with respect to future generations. The proposed definition can be considered a valuable complement to the recently emerged nested system discourse of sustainable development, by offering a more quantitative tool to monitor and guide the transition of human society towards a harmonious relationship with the rest of the biosphere.

Keywords: anthropocene; Brundtland; dissipation; ecocrisis; entropy; exergy; pareto; resilience; self-organization; transition

1. Introduction

Sustainable Development as defined by the Brundtland Commission [1]—development that meets the needs of the present without compromising the ability of future generations to meet their own needs—was the hopeful but paradoxical concept which made the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro an unprecedented success in global cooperation. Hopeful, because it held the promise of developing the world's majority of people living in poverty. Paradoxical, because it aimed at reconciling the right of development of every world citizen with the global environmental burdens associated with the current development model.

The Brundtland definition was a milestone on the long trajectory of humanity's quest to increase and sustain prosperity in the long term without disrupting the natural resource base on which it has developed (cf. [2]). New to this definition was however the notion of (intergenerational) solidarity between people (e.g., [3]), which adds a social dimension to the economic and environmental dimensions of sustainable development (further denoted as SD).

Unfortunately, this commonly adopted three-pillar model of sustainable development [4] (Figure 1) has not shown sufficient effectiveness for acting within planetary boundaries [5]. The observation that the thresholds for several planetary equilibria have been passed (see e.g., [6]) illustrates the failure of the pillar model, and implies the adoption of an alternative sustainability model. There is increasing understanding that global environmental quality is a non-negotiable boundary condition for the economic system [7]. Obviously, something more fundamental has to change in the overall strategies of production, consumption and organizing markets [8]. Therefore, a nested sustainability model considering human society and its economy as a subsystem nested in the planetary ecosystem [5,9] (Figure 1) seems a more adequate basis for initiating and implementing a transition towards planetary stewardship [10].

The success of the currently dominating pillar discourse is in its vagueness [11]. Worldwide sustainable development acquired a common connotation of being something important and positive, while leaving large flexibility of attributing very different meanings to it among different segments of society [12]. But in a Rio+20 context of globally dwindling commitment to the cause of SD this vagueness has proven to be at the core of its weakness. The weak scientific fundaments of the definition has led to the often arbitrary selection of sustainability criteria and indicators, and consequently to poor monitoring and compliance. The focus on intergenerational equity got stuck in economic debate on the social discount rate to consider (e.g., [13,14]). Meritorious efforts have been made to build sustainability indicators on more solid scientific grounds (e.g., [15,16]), including the concepts of environmental space [17] and ecological footprints [18]. Despite these efforts, SD has become a giant with feet of clay. To revitalize the concept there is a clear need to promote the nested system discourse mentioned above, but this also implies revisiting the definition with more scientific rigor.

In this article we revisit the challenge of SD from the emerging scientific field of complexity science. We propose a more functional and science-based redefinition of SD based on recent advances in complex social-ecological system analysis and supporting the nested systems model of SD. We then discuss the operational advantages and possible pitfalls of the new definition.

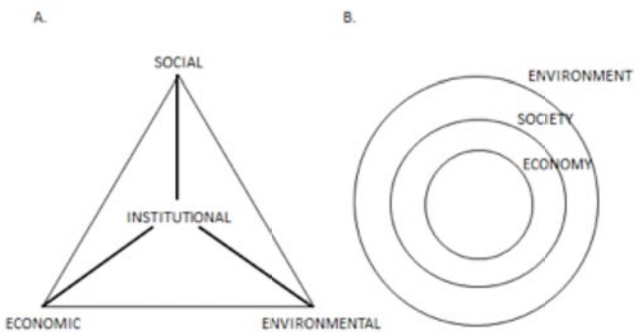

Figure 1. Comparison between the two principal models of sustainable development (after [19]). A. The pillar model; it originally had three pillars (economic, social, environmental) but many authors adopted a fourth institutional pillar. B. The nested systems model; the economy is at the service of human society, which in turn needs to operate within the biophysical boundaries of the planetary ecosystem [5].

2. Background and Scientific Basis for a New Definition

2.1. Fundamental Changes in the Social-Ecological System

The relationship of humanity with nature changed fundamentally between the onset of the Holocene period about 12,000 years ago and today. Human societies developed from small groups of hunter-gatherers through larger farming/agricultural communities to global urban-industrial society [8,20]. Larger complex societies led to a more efficient buffering of external and internal disturbances and thus to more prosperity and well-being. From an energetic point of view, this evolution of mankind from a modest role in the food web to the prominent ecosystem engineer was characterized by a regime shift in metabolic profile, characterized by an increase in per capita daily caloric energy consumption by more than a factor of 50 [8,21]. This was the consequence of agricultural and industrial revolutions, which complemented manpower with horsepower and later machine power. This improved the human condition to such an extent that an increase in human population with by a factor of more than 10,000 occurred. The resource needs to sustain such a large complex system have grown far beyond what nature or agricultural production can provide, and non-renewable resources external to the biosphere (e.g. petrol and uranium from the geosphere) have been discovered and are being exploited to meet these needs [22]. These fundamental differences in the energetic relationships to nature between hunter/gatherer, agrarian, and industrial-urban societies are visualized in Figure 2.

2.2. The Ecosystem Exergy Concept

In section 2.1 the crucial role of energy flows to sustain complex human societies was explained. Thermodynamics is therefore a suitable discipline to describe the macroscopic behavior of complex living systems. Early scholars including Lotka, Schrödinger and Prigogine have developed the basics for thermodynamics of such open systems. Schneider and Kay [23] formulated the ecosystem exergy concept (exergy is useful energy able to do work; it can be consumed in contrast to energy; it is often what people mean when using the word energy; see [24] for a review) as a holistic descriptive model of the behavior of complex living systems far from thermodynamic equilibrium. It basically comprises four essential elements: a) Ecoystems are open systems exposed to exergy fluxes (mainly solar radiation). b) Like a dam in a river, ecosystems accumulate part of that incoming exergy to increase their own exergy content (Schrödinger's order from disorder premise, [25]). c) Ecosystems with higher exergy content are more effective dissipative structures, i.e. dispose of a larger buffering capacity against destructive exergy fluxes such as radiation, wind, rain, and nutrient and sediment loss. Buffering is defined here as any physical or chemical activity at the disposal of a system to reduce a gradient imposed on it (see [23]). Forest ecosystems for example buffer against sunlight and destructive rains with their canopy structure, and against the leaching of nutrients and erosion with their root network; the buffer capacity depends on the quality of the filter, i.e. the density and equal distribution of leaves and roots. d) It is crucial to understand that improved buffering in an ecosystem leads to improved chances on survival and thus to evolutionary advantage, and is as such a motor of evolution: ecosystems improve and keep their capacity to create order and dissipate exergy by Darwinian selection and transfer of genetic information to subsequent generations (order from order).

In this model, exergy maximization is considered a goal function of ecosystem development, which leads, in the absence of large disturbances, to increased control over energy and matter flows. This model concurs with the ecosystem succession model of Odum [26] and Bormann & Likens [27], and is supported by thermal remote sensing observations [28-30]. It does not conflict with the second law of thermodynamics, because the local increase of exergy in open dissipative systems leads to more effective dissipation and, as a matter of fact, to an increase of entropy of the global system, in which the ecosystem is embedded [31].

Social scientists (e.g., [20,32]) independently came to a similar insight that the thread of human evolution is towards larger societies with more complex institutional organizations leading to stronger collective protection against human suffering of all kinds. This remarkable parallel in structure and function between ecosystems and human systems is illustrated in Table 1. The ecosystem exergy concept proves to be a powerful model to describe the relationship between the structure and function that ecosystems and human societies have in common with Carnot's law for closed systems: the higher the exergy availability of a system, the higher its potential to perform work. Complex systems can basically: 1) store exergy and keep it available for one or more of the following uses (storage also implies a risk of loss, e.g. forest biomass accumulation leading to increased fire loss); 2) use it for maintenance (as survival depends on it, it is typically a priority allocation); 3) for buffering (as it offers collective long-term survival perspectives, it is an important driver of co-evolution for the different elements of the system); or 4) for luxury consumption (this is exergy consumption not leading to one of the former two outcomes, and that in an evolutionary perspective will ultimately get eliminated by selection pressure). Buffering leads to better fitness of the system and is therefore a fundamental principle of self-organization. We therefore name our world where ecoystems and human systems co-exist *bufferworld*.

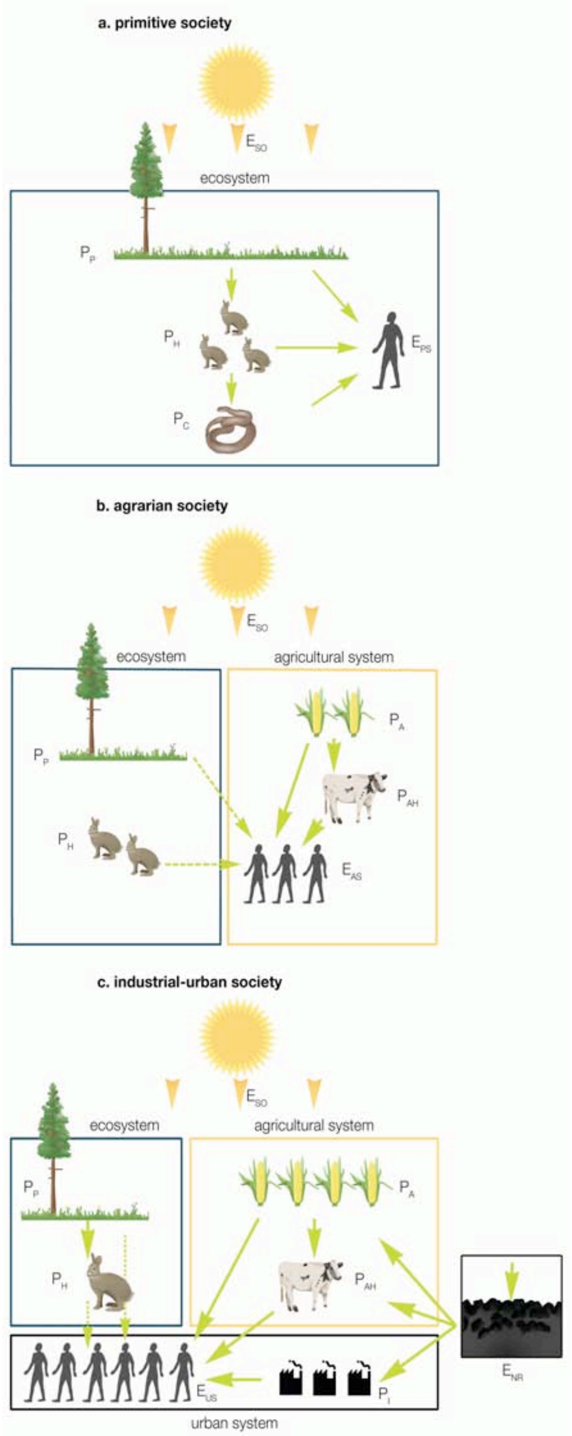

Figure 2. A simplified representation of the energetic relationships between mankind and nature in a) a primitive society; b) an agrarian society; and c) an industrial-urban society (after [33]). Legend of symbols: E_{SO} = incoming solar energy; P_P = primary production of plant biomass in the ecosystem; P_H = production of herbivores in the ecosystem; P_C = production of carnivores in the ecosystem; E_{PS} = energy needs of the primitive society; P_A = primary production in the agricultural ecosystem; P_{AH} = production of herbivores in the agricultural ecosystem; E_{AS} = energy needs of the agrarian society; E_{NR} = non renewable energy sources; P_I = industrial production; E_{US}= energy needs of the urban society. Dashed, resp. dotted lines indicate fluxes of relatively decreasing importance, which in absolute terms may be increasing. Note that through the evolution from primitive over agrarian to industrial-urban society the human population increases, the area of (semi-)natural systems decreases in favor of agricultural and urban land; wildlife decreases and large predators become extinct.

3. Proposal for a New Definition

3.1. The Anthropocene

Human communities form part of the biosphere and have always been heavily dependent on resources extracted from the ecosystem for their exergy provision, and on other ecosystem services for their buffering (Figure 2). In recent history humans discovered and used extensively more concentrated exergy sources exogenous to the biosphere (coal, petrol, natural gas and uranium from the geosphere). Apart from the risk of depletion, their consumption causes toxic or climate forcing emissions, which provoke disturbances in the biosphere. Meanwhile their use greatly increases the power of humans to modify the biosphere. As a consequence, increasing amounts of land gradually or abruptly change from the sphere of nature dominion to increasing human dominion [17,34,35]. It makes the protective vegetation canopy thinner and scarcer, undermining its buffering capacity for light, heat, wind, rain and dust. Human efforts to concentrate solar exergy in useful target crops through intensive agriculture, forestry and biocide use are leading to an overall simplification of the biosphere (see e.g., [36]). Human development-induced changes in biogeochemistry and atmospheric composition at planetary scale are large enough to consider the onset of a new geological era, called anthropocene [37].

A thermodynamic interpretation of the anthropocene would be that the human society is increasingly behaving as a separate system, which means that it increases its order at the expense of the order in the biosphere. The current development of human society is causing a trade-off with entropy production in its environment, which is threatening the buffering capacity of the biosphere in the long term. Anthropogenic entropization of the biosphere is the essence of the ecocrisis in bufferworld. Considering the heterotrophic metabolism of humans and the large dependence of human society on ecosystem services [38] (Figure 3), it must be emphasized that human society is a subsystem nested in the biosphere. It is not viable without the ecosystem, while the ecosystem is viable without human society. As a consequence, this evolution seems more worrisome for mankind than for the biosphere in general.

Table 1. The ecosystem exergy model of Schneider & Kay [24] as the universal goal function of complex self-organizing systems, here applied to ecosystems and human society, illustrating the analogy in structure and function between the two systems.

	Ecosystems	Human Society
Goal function	Max[buffer exergy flows] through max[exergy content]	Max[buffer exergy flows] through max[exergy content]
Main exergy source	Solar exergy	Ecosystems, fossil fuels
Exergy storage[1]	Biomass, genetic diversity, diaspores, foodwebs and other ecosystem structures	Food reserves, houses, money, social and institutional structures, other capital and assets
Memory and information transfer[2]	DNA	DNA, oral and written information, bits and bytes
Exergy dissipation (Buffer function)	Buffering against sunlight, temperature change, nutrient loss, water runoff, sediment loss, wind damage	Shelter against climatic extremes, internal and external threats in terms of conflict, hunger, disease, natural and technical disasters

[1] See [25], supplementary material S4 for a discussion on the exergy content of information. A tree seed has much lower exergy content than an adult tree weighing 5 tonnes, but it holds the potential to accumulate a similar amount. Also, money is an important carrier of exergy, which can be exchanged at any time against exergy for maintenance or to perform buffer work.
[2] Memory and information transfer are essential to share successful experiences of exergy accumulation and exergy buffering with conspecifics of the next generation. Plants transfer information mainly through DNA, while vertebrate animals show plenty of learning methods in addition to genetic transfer. Although the hereditary intelligence of humans is not very much higher than that of apes, the revolutions of non-genetic information transfer through oral and written communication have boosted their progress in exergy capture and exergy buffering.

3.2. The Definition

Based on the former, we define Sustainable Development as the increase of the exergy content and exergy buffering of human society, not provoking a measurable decrease of exergy content and exergy buffering of the ecosystem. This scientific definition is valid and applicable for social-ecological systems at different scales of time and space, e.g. over a decade at the level of a local community with its surrounding landscape, or on an annual basis at the level of the world community with its global natural resources. This can be easily translated into everyday language as the increase of human prosperity (exergy content) and human well-being (exergy buffering) without the loss of ecosystem structure (exergy content) and ecosystem functioning (exergy buffering). In short it is development that does not degrade the biosphere. It is important to observe that both the human and the ecosystem side of the definition have a structural and a functional component: human prosperity and ecosystem structure and composition as the structural component (exergy content, order); human well-being and ecosystem function as the functional component (exergy dissipation, bufferwork). As mentioned earlier exergy content and exergy dissipation are related but not linearly: exergy content is a necessary condition to perform bufferwork (no well-being without capital), but inversely, exergy content has many options, as it can be used as a reserve, maintenance, luxury consumption or buffering. Buffering can also be the mere consequence of the presence of dissipative structures. Especially on the human side, the build-up of capital with a limited increase in overall societal buffering capacity has been common in the history of mankind, and has been extensively debated in classical socio-economic literature. Indicator selection should therefore include both prosperity (economic pillar) and well-being (social pillar) aspects to measure human development.

The foregoing has made clear that increasing the prosperity and well-being of human society often implies the extraction of resources from ecosystems, emissions into ecosystems, and competition for space, and will thus often be at the expense of their structure and function. These trade-offs between human society and ecosystems suggest the existence of a set of optimal solutions as a compromise between human development and ecosystem development. Technically speaking, the new definition is the result of an optimization exercise, that is searching for efficient solutions along a Pareto front formed by the trade-off between human prosperity and well-being and ecosystem structure and function (Figure 4). In Figure 4 we can see how sustainable development can move the system to improved human prosperity and well-being under a status quo or an improvement of the ecosystem structure and function, until it reaches a new state (the Pareto efficient solution) where further human development would unavoidably lead to ecosystem degradation. It becomes obvious that sustainable development (development without the loss of ecosystem structure and function) is a difficult challenge, and does not seem achievable with technical measures alone or isolated project-wise actions within the current institutional context, but would need a large societal transition accompanied by a global institutional reform [8,41]. Such a transition should lay the basis for a more harmonious co-evolution between humans and ecoystems as a unified social-ecological system inhabiting the biosphere. Possible elements of such a transition are captured by the proposed definition: an increase of resource efficiency (creating more prosperity and well-being with less input or output

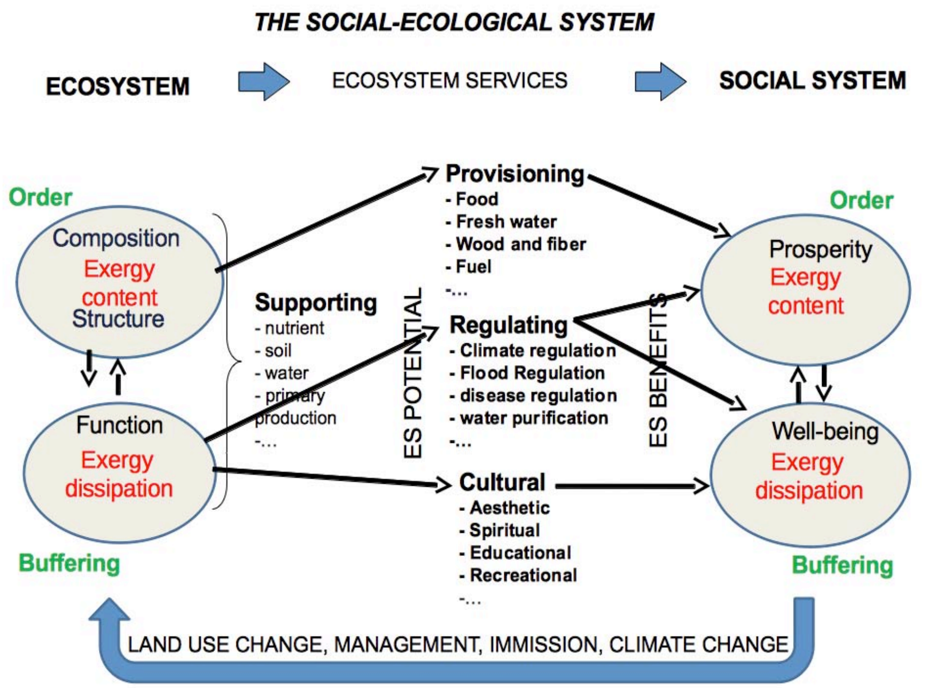

Figure 3. Conceptual scheme showing the relationships between ecosystems and social systems as closely interlinked subsystems of the overarching social-ecological systems occurring in the biosphere. Both subsystems develop a structural/compositional component (exergy content), which provides exergy to their functional component (buffering). The composition, structure and function of the ecosystem offer a potential source of ecosystem services to human society [39,40], which may use the ecosystem service benefits to increase prosperity (the economic pillar of development) and well-being (the social pillar of development). The feedback arrow at the bottom illustrates that ecoystems are heavily shaped by deliberate and unintended human influences.

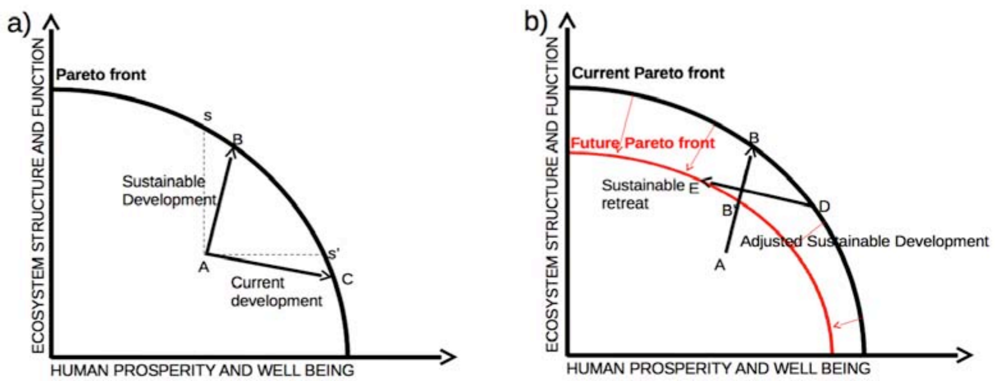

Figure 4. Sustainable development as an optimization exercise between human goal functions and ecosystem goal functions. a) The Pareto front is the set of efficient solutions (it means solutions where further human development would unavoidably lead to ecosystem damage, and vice versa). Trajectories from a present non Pareto-efficient situation A to B and C show the main development options. Trajectory AB evokes the challenge of sustainable development, increasing human goals without decreasing ecosystem goals. All trajectories between As and As' are Pareto efficient and therefore sustainable. Trajectory AC shows the current development trend, which is outside the trajectory range between As and As' and therefore unsustainable, given that it increases human goals while decreasing ecosystem goals. b) As a consequence of anthropogenic environmental degradation the current Pareto front may shrink to a future Pareto front with lower potential exergy buffering for both sub-systems. Under such a regime shift (cf. Section 5.2) an effort of sustainable development AB will end up as an inferior adjusted sustainable development AB' (cf. [41]). Lovelock [42] considers that we are now already in a situation where further development without environmental damage is no-longer possible (this means that we are on or above the Pareto front) and where the shrinking resource base urges for a so-called sustainable retreat to a lower future Pareto front, which can be visualized by the trajectory DE.

related impact on the structure and function of the ecosystem), the replacement of overconsumption by a more frugal lifestyle (decreasing ecosystem impacts caused by prosperity that does not contribute much to well-being), and setting safeguards on vital ecosystem structures and functions (implementing caps on human development where it directly affects vital ecosystem structures and functions).

This definition is transparent and functional. Anchored in the laws of thermodynamics it allows the selection of quantitative indicators (see Section 4).

4. Indicators and Application

Rather than presenting a concrete indicator set, some guiding principles are formulated as to the selection and processing of indicators based on the new definition of SD. Sustainability is evaluated for a given social-ecological system with defined system boundaries over a certain period of time, by comparing human development (change of prosperity and well-being over this time period) with ecosystem development (change in structure and function over this time period), which can be written as:

$$\frac{I_{PW,t_1} - I_{PW,t_0}}{I_{ESF,t_1} - I_{ESF,t_0}} \quad (1)$$

where I_{PW} is the selected indicator for human prosperity and human well-being (remember that, thermodynamically speaking, this corresponds respectively to the exergy content and exergy buffering of the human system), I_{ESF} the selected indicator for ecosystem structure and ecosystem function (remember that these are respectively the exergy content and exergy buffering of the ecosystem), t_0 and t_1 the start and end of the considered evaluation period.

Basically the sustainability check of equation (1) has four possible outcomes:

- Increase in numerator and denominator: sustainable development;
- Increase in numerator and decrease in denominator: unsustainable development;
- Decrease in numerator and increase in denominator: sustainable retreat;
- Decrease in numerator and decrease in denominator: unsustainable stagnation.

The magnitude of the obtained ratio in comparison with values from other regions or time periods allows interpretation of how sustainable or unsustainable the observed development is. This is possible for contemporary studies (e.g. annual monitoring of human prosperity and well-being and ecosystem structure and function in a Brazilian catchment after inaugurating a new dam), retrospective analysis of human development in the past (e.g., calculating sustainability in Roman and Byzantine periods based on forest resource modeling modulated by population density estimates from archaeological evidence for an ancient city excavated in Turkey), or prospective analysis of human development in the future (e.g., modeling the biodiversity loss caused by climate change for different IPCC SRES scenarios based on scenarios of human development, see [43]).

As such, this approach sets a framework for continuous monitoring and improvement, rather than proposing fixed sustainability thresholds. This makes sense, because as a consequence of regime shifts, which are inherent to complex social-ecological systems (Figure 4b and Section 5.2), sustainable development is a moving target. But Rockström et al. [6] argue that to avoid unwanted regime shifts in the biosphere, thresholds must be placed on vital biophysical conditions that determine the safe space within which humans can operate. Putting a minimum threshold level on ecosystem exergy content and dissipation is perfectly possible within the here proposed framework.

Note that numerator and denominator are not necessarily in the same units, unless exergy analysis would be applied. In practice analysts may want to work with proxy indicators having different units, e.g., Gross Domestic Product (GDP per capita in monetary units, $ per capita per annum) for human prosperity and well-being (in fact , the GDP per capita, also called the standard of living is not a proxy of the exergy content but of the annual exergy inflow in the human system, which can be used for maintenance, increase in prosperity, and increase in well-being) and e.g., protected area (in km^2) or free Net Primary Production (fNPP, in ton per ha per annum, cf. [44,45]) for ecosystem structure and function (in fact, the fNPP is not a state indicator but measures the fraction of the annual increase in ecosystem exergy content that is not extracted by humans), or may want to work with dimensionless composite indicators like e.g. Inequality Adjusted Human Development Index (cf. [46]), Genuine Progress Indicator (cf. [47]) or Gross National Happiness (cf. [48]) for human prosperity and well-being (although the latter already includes ecosystem fitness).

A large remaining challenge is the development of indicators for ecosystem structure and function. In fact, the effects of human activity on ecosystem composition, structure and function are, thus far, poorly understood. As a consequence, indicators and monitoring instruments for ecosystem structure and function are still largely underdeveloped, and multitemporal information of ecosystem trends are hardly available. According to Rosen [49] it is a big asset of ecosystem exergy analysis that it can measure the increase in disorder in ecosystems associated with human environmental impact. Odum [27] was one of the first to propose an indicator set for measuring ecosystem maturity based on ecosystem thermodynamics. Several other indicators measuring the degree of self-organization, integrity or naturalness of ecosystems have been proposed ever since. Bendoricchio and Jørgensen [50] came up with an elegant formula to calculate the exergy content of ecosystems including the exergy content included in its biodiversity. This formula was criticized as thermodynamically incorrect (e.g., [51]), but was later recycled as a calculation of eco-exergy, a proxy for ecosystem exergy content useful for accounting purposes. Others developed indicators for solar exergy dissipation by ecosystems, based on the evaluation of their energy balance (e.g., [30,52]). There is also a long tradition of trying to give monetary value to ecosystems and ecosystem services, which is potentially a good proxy of ecosystem exergy content and buffering. But it is important to recognize the important limitations of economic valuing, including the poor methodological development of valuing biodiversity and biodiversity function, and the serious limitations of the ceteris paribus principle of partial equilibrium when upscaling value to the global level (cf. the criticized global valuing of ecosystem services like pollination by [53]). For the time being, end point indicators of changes in ecosystem state and function in the denominator of equation (1) can be replaced by mid-point indicators of human input-related (resources use) and output-related (emissions) impacts, or inversely, of human efforts towards sustainability, like efficiency indicators. Another complication of selecting indicators is the problem of spillover and double counting. Spill-over happens when a selected indicator does not include all aspects of human or ecosystem development and, as a consequence, shows externalities. A concrete example is the use of forest transition [54] as a sign of sustainable development. The forest index of countries typically evolves from a trend of more people, less trees in the early stages of development (positive numerator and negative denominator in our formula = unsustainable development) to a trend of more people, more trees in later stages of development. The explanation of this geographical theory is however leakage and spillover: in later stages of development countries increasingly thrive on imported carrying capacity (wood imports from neighboring countries with a lower standard of living is exporting the deforestation problem, see [55], and on converting the energy system from wood-fuel to fossil fuel turning the input-related environmental impact into an output-related environmental impact. Double counting is a typical problem of using indicator baskets. In the land use impact method used in Garcia et al. [56] for example, Leaf Area Index is used as an indicator of ecosystems structure (exergy content) and soil erosion is used as an indicator of ecosystem function (exergy dissipation), but the soil erosion buffer is a direct consequence of the presence of a large leaf area.

5. Discussion

5.1. Focus and Functional Strength of the New Definition

The revised definition of SD has a more solid scientific background than earlier ones, which facilitates the selection of indicators that are not arbitrary, but that quantify the exergy content and exergy dissipation of both human and ecosystem subsystems of the social-ecological system.

The system boundaries for global SD assessment are set to the biosphere, the vital space for life on earth (or to part of the biosphere for SD assessment at a smaller geographical level). The geosphere is excluded, which means that in contradiction to some impact methods (cf. [57]) the use of fossil fuels or ores is not considered an environmental burden, but obviously the impact on the ecosystem of careless extraction and emissions as a consequence of its use are considered a burden.

Different from the Brundtland definition, the revised definition does not focus on the trade-off between present and future generations of humans, but rather on present, past and future trade-offs between humans and ecosystems. This is similar to the definition recently published by [5]. One could say that this approach is less anthropocentric than the Brundtland definition and other definitions along the line of the pillar discourse, as it proposes equal interests for humans and ecosystems. Since humans depend on ecosystems, the state of the ecosystem partly reveals the fate of future generations of humans. But only two of the nine planetary thresholds that [6] use to determine the safe operating space of humans to avoid a catastrophic shift in the planetary metabolism are directly related to ecosystem structure and function (biodiversity loss, change in land use), while the seven others (climate change, ocean acidification, stratospheric ozone depletion, nitrogen and phosphorus cycles change, global freshwater use, atmospheric aerosol loading and chemical pollution) are, albeit interlinked with ecosystems, physical-chemical state and rate variables that will affect both humans and ecosystems of the future. This means that planetary stewardship (see [58]) needs to consider effects of present development on both present ecosystem structure and function and future human and ecosystem development. In that sense, the indicator set linked to the denominator of equation [1] should not be limited to the structure and function of the ecosystem, but it is recommended that it includes also physical/chemical state indicators of the overall social-ecological system.

5.2. Determinism versus Stochasticity

The exergy concept shows several parallels with the ecosystem succession theory of Odum (1969) [26], which has been criticized for being unidirectional and deterministic. In reality stochastic phenomena make the behavior of social-ecological systems largely unpredictable, and disturbances have to be considered inherent to the existence of ecosystems. Kay [59] showed that the ecosystem exergy concept is not in contradiction with chaos theory and the occurrence of alternative stable states [60]. The panarchy model for the ecological and social systems of Gundersen & Holling [61] very satisfactorily links the deterministic components of ecosystem thermodynamics with the stochastic aspects of chaos theory into one single theory. By adding an extra dimension of resilience to the trend of exergy increase during a process of self-organization, they are able to clarify how disturbance is inherent to complex systems: increasing order and fine-tuning the bufferwork to the small recurrent disturbances, the system is losing resilience, and becomes fragile and sensitive for catastrophic shift to a different state. Figure 5 illustrates how the existence of such stable states in both human systems and ecosystems complicates the goal setting of sustainable development.

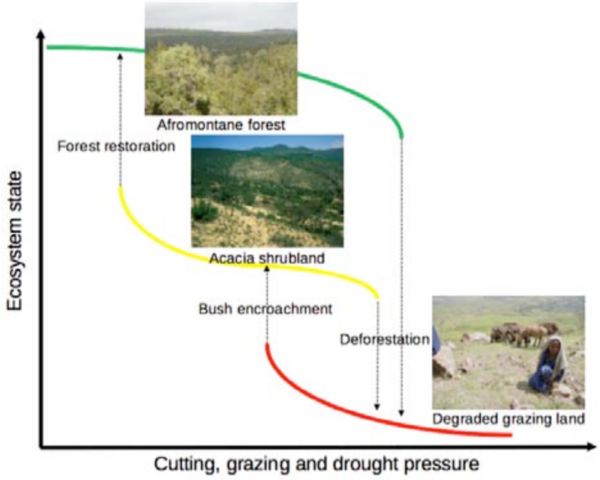

Figure 5. Example based on observations from [62] of an extremely non-linear response of ecosystems to pressures caused by human development, giving existence to alternative stable states and making sustainable development a moving target. The Afromontane Forest of semi-arid northern Ethiopia is well buffered against the effects of human development, but beyond a certain threshold the forest collapses and changes into degraded grazing land. If forest restoration efforts are made, it appears that restoration only becomes possible at much lower pressures than the collapse occurred, and restoration does not directly result in the recuperation of the original vegetation but in a bush state with lower ecosystem services than the original forest. This phenomenon of non-reversibility is called hysteresis, and is a typical indication of alternative stable states.

The panarchy theory is a good basis to explain the efforts needed for a transition towards sustainable development. The loss of resilience in mature complex systems is congruent with the so-called institutional lock-ins described in transition theory [63]. Transition only boosts when innovation niches are created through institutional reforms focusing on the increased resilience of society and ecosystems [64-66]. This means that the transition pathway towards sustainable development could pass through phases where the order or buffer capacity of the human society temporarily decreases, while the resilience increases. In order to evaluate the success of a transition process, it is therefore recommended that monitor resilience indicators of the social-ecological system as a whole is also carried out, in addition to equation (1).

6. Conclusion

The proposed definition of sustainable development completes the nested systems discourse on sustainability, which considers that socio-economic development needs to operate within the safe operating space defined by planetary boundaries. It is a science-based functional definition, which facilitates the selection of indicators, and the development of simple measuring tools for the evaluation of complex social-ecological systems. It can serve as an operational support to assess the progress along the transition pathway towards a sustainable society. It hopes to contribute to moving sustainable development away from a fuzzy contradiction in terms towards an objective optimization problem between the human system and the ecosystem, two strongly interlinked sub-systems, nested in the overall social-ecological system, and showing fundamentally similar patterns and processes of structures and functions for buffering. It finally holds an active invitation for human society to make a transition to more harmonious development as part of the social-ecological system rather than autonomous development at the expense of the ecosystem.

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