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How to understand and measure environmental sustainability: Indicators and targets

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ABSTRACT

The concept of sustainable development from 1980 to the present has evolved into definitions of the three pillars of sustainability (social, economic and environmental). The recent economic and financial crisis has helped to newly define economic sustainability. It has brought into focus the economic pillar and cast a question mark over the sustainability of development based on economic progress. This means fully addressing the economic issues on their own merits with no apparent connection to the environmental aspects. Environmental sustainability is correctly defined by focusing on its biogeophysical aspects. This means maintaining or improving the integrity of the Earth's life supporting systems. The concept of sustainable development and its three pillars has evolved from a rather vague and mostly qualitative notion to more precise specifications defined many times over in quantitative terms. Hence the need for a wide array of indicators is very clear. The paper analyses the different approaches and types of indicators developed which are used for the assessment of environmental sustainability. One important aspect here is setting targets and then "measuring" the distance to a target to get the appropriate information on the current state or trend.

1. Sustainable development

The term "sustainable development" was coined by the IUCNís 1980 World Conservation Strategy (IUCN, UNEP and WWF, 1980). It stated that "for development to be sustainable it must take account of social and ecological factors, as well as economic ones". Our Common Future (Brundtland Report) (WCED, 1987) then gave further direction to comprehensive global solutions. It defined sustainable development as development which "meets the needs of the present generation without compromising the ability of future generations to meet their own needs". This has since become an often-quoted definition. The definition was extended by the Earth Summit in 1992 (UN, 1992a). It produced the 40 chapters (150,000+ words) for Agenda 21. The formalization was completed by the World Summit on Sustainable Development in 2002 (UN, 2002) with the notion of the three pillars – social, environmental, economic – as symbolized by the summit motto "People, Planet, Prosperity". At present, the term itself and its tenor have become so widespread and well-known that we may take it as common sense. Moreover, it is inevitably incorporated into any important political, business, or other strategic document (e.g. most of the fundamental documents of the European Union, including the recent Lisbon Treaty (EU, 2007).

Needless to say, in cited documents as well as in many others (e.g. see Bell and Morse, 1999), the meaning of sustainable development and sustainability is not identical, even though the fundamental sense is basically the same. While sustainability denotes a system property referred to as quality, we believe that the key to the sustainable development concept is provided by the already quoted Brundtland definition and Article 1 of the Rio Declaration (UNCED, 1992): "Human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature". The message of these two fundamental documents could be summarized in three brief points.

Firstly, the idea of sustainable development is a pragmatic and anthropocentric one. It primarily focuses on people and their well-being. At the base of sustainability are our needs. One approach, known as Maslow's Pyramid, assumes that human beings are motivated by unsatisfied needs. Certain basic needs must be fulfilled before higher needs can be satisfied (Maslow, 1968, 1999). According to Maslow, there are universal needs (physiological, survival, safety, love, and esteem) that must be fulfilled before a person can act unselfishly. This foundation for unselfish behavior could certainly then be seen as one of the conditions for accomplishing sustainable development. We would agree with the essential elements of human well-being stipulated in the Millennium Ecosystem Assessment (2005). These were security,

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the basic material for a good life, health, good social relations, and freedom of choice and action.

Secondly, human life should be "healthy, productive and in harmony with nature". This principle implies a quest for balance among the three sustainable development pillars. Human life is neither independent nor isolated; it is part of a complex web of natural and social phenomena and depends on a myriad of relationships and interdependencies. In particular, the necessary "harmony with nature", which addresses the environmental pillar, is stressed.

Thirdly, another essential feature of sustainability is dynamic and long-term nature. The formulation takes into account "present and future generations" and simultaneously points out the changing situation and emphasizes concerns for the future without any explicit time limit or target. The time dimension is tied to the average human life and emphasizes a necessary extension – possibly a very long extension – above and beyond it. These three simple principles apply to all three pillars.

The rather broadly defined notion of sustainability was historically understood as mostly environmental sustainability, as evinced by the already quoted World Conservation Strategy (IUCN, UNEP and WWF, 1980). The strategy believed that humans must recognize the world's nature resources as finite, with limited capacities to support life. The objective, then, is to conserve natural resources to ensure continued development and to support all life. Even recently, the European Union's Gothenburg Sustainable Development Strategy approved in 2001 and the renewed version endorsed again in 2006, placed four out of its six main objectives more or less within the environmental realm: climate change and clean energy, sustainable transport, sustainable consumption and production, conservation and management of natural resources, and public health. The other two pertained to social inclusion: demography and migration, and global poverty and sustainable development challenges (EU, 2006).

1.1. *Economic sustainability*

Gradually, however, the other two pillars have been discussed more thoroughly. The economists focus on various kinds of "capital" (man-made, natural, human, social) that should be sustained (World Bank, 2006). Another approach is based on the Goodland-Ledec specification of sustainable development (Goodland and Ledec, 1987). Sustainable development means the use of renewable natural resources in a manner that does not eliminate or degrade them or otherwise diminish their usefulness for future generations. Furthermore, it implies using non-renewable (exhaustible) mineral resources in a way which does not unnecessarily preclude easy access to them by future generations. Finally, it requires a sufficiently slow-rate of depletion of non-renewable energy resources to ensure the high probability of an orderly societal transition to renewable ones. This definition focuses primarily on the physical aspects of sustainable development. Other approaches focusing on optimal resource management, propose, for example, the definition by Markandya and Pearce (1988). According to this definition, sustainability might be redefined so that the use of resources today should not reduce real incomes in the future because sustainability requires that the conditions necessary for equal access to the resource base be met for each subsequent generation. Or "Natural resources and the environment constitute the ultimate foundation upon which all future economic activity must be construed. From this, it follows that future economic progress will be increasingly dependent on the sustained integrity of the resource and environmental base." (Hamrin, 1983).

Recently, well-being has been recognized as a pivotal notion in the context of sustainable development. Well-being is understood as any act of consumption which includes the enjoyment of any goods or services. Goods and services can include things freely provided by nature, such as a beautiful sunset. Sustainable development means increasing "consumption", following its broadest economic interpretation, over a very long time (OECD, 2008a).

Given the current financial and economic crisis, the economic aspects of development are under close scrutiny. The economic crisis shows that maintaining economic growth is an essential and universally accepted objective for the broad public. It should be noted that growth has been the most important policy goal across the world for the last five decades. It is the reason why it has been difficult to find a balance between sustainability and the economic growth of countries. Hopefully, the economic crisis could be an example of how to change the approach to economic growth and how to conceive of a new economy in terms of sustainable development. An example of such an approach may be the study "Prosperity without growth?" by Tim Jackson (2009) or "Managing Without Growth" by Peter A. Victor (2008).

The importance of economic sustainability is now increasingly recognized even by top political representatives. The U.S. President B. Obama has stated recently: "It is simply not sustainable to have an economy where, in one year, 40 per cent of our corporate profits came from a financial sector that was based on inflated home prices, maxed-out credit cards, over-leveraged banks and overvalued assets." (Klein, 2009). The current global economic crisis thus brought into focus the economic pillar and questioned the sustainability of development based on economic progress. This means fully addressing the economic issues on their own merits and in no apparent connection with the environmental aspects.

1.2. *Social sustainability*

The approaches to the social dimension of sustainable development are as diverse as the approaches to the economic pillar. As mentioned by Martin, a specific definition of the social dimension of sustainable development is less clear-cut (Martin, 2001). Understandably, the diversity of economic, social and cultural conditions in individual countries makes development of a uniform definition of social sustainability very difficult. Black defined social sustainability as "the extent to which social values, social identities, social relationships and social institutions can continue into the future" (Black, 2004). Torjman characterizes social sustainability as follows: "From a social perspective in particular, human well-being cannot be sustained without a healthy environment and is equally unlikely in the absence of a vibrant economy" (Torjman, 2000). Gilbert et al. perceive the social pillar of sustainable development as follows: "Social sustainability requires that the cohesion of society and its ability to work towards common goals be maintained. Individual needs, such as those of health and well-being, nutrition, shelter, education and cultural expression should be met" (Gilbert, 1996).

However, these and other definitions are more or less statements of the general goals of social policy rather than serious attempts to define the social dimension of sustainable development, as noted by Colantonio (2007). And yet, it is precisely the social "pillar" of sustainable development that is probably the most important and critical for the long-term survival of human civilizations as shown in Jared Diamond's insightful study of past (and contemporary) societies (Diamond, 2005). Another somewhat indirect basis for this view is the finding of the authors of The Wealth of Nations (World Bank, 2006 – see below) that human and social capital is the most important component of national wealth.

Despite this recognition, it is not yet fully clear what the critical elements of social unsustainability are. Is it growing, or at least not diminishing, inequality among people, regions or nations? Is it good health in a broad sense? What does this imply about the sustainability of health care systems? Is it the malfunctioning of national institutions as documented by the Failed States

Index (Foreign Policy, 2009)? According to that document, are we to say that Somalia, Sudan or Zimbabwe are not sustainable countries?

1.3. Environmental sustainability

Sustainable development used to be more or less understood as social and economic development that should be environmentally sustainable. Since the "three pillars" concept was introduced, it has gradually been acknowledged that economic and social sustainability do indeed have their own merits, as well as specific and concrete meaning as a part of human, social, political or economic development. In light of such understanding, it is necessary to closely scrutinize the third pillar to focus on the definition of environmental sustainability and ask for a full clarification of its precise meaning.

The term itself was probably first coined by scientists at the World Bank. Originally, the term "environmentally responsible development" was used (World Bank, 1992). Subsequently, "environmentally sustainable development" was employed (Serageldin and Streeter, 1993). Finally, the concept of environmental sustainability was developed (Goodland, 1995).

According to Goodland, environmental sustainability "seeks to improve human welfare by protecting the sources of raw materials used for human needs and ensuring that the sinks for human wastes are not exceeded, in order to prevent harm to humans". Goodland's conceptualization of environmental sustainability fits into the resource-limited ecological economic framework of "limits to growth". He also identifies environmental sustainability as a set of constraints on the four major activities regulating the scales of the human economic subsystem: "the use of renewable and non-renewable resources on the source side, and pollution and waste assimilation on the sink side". Holdren et al. (1995) define environmental sustainability by focusing on its biogeophysical aspects. Biophysical sustainability means maintaining or improving the integrity of the life supporting systems of the Earth. Sustaining the biosphere with adequate provisions for maximizing future options includes enabling current and future generations to achieve economic and social improvement within a framework of cultural diversity while maintaining (a) biological diversity and (b) the biogeochemical integrity of the biosphere by means of conservation and proper use of air, water, and land resources.

The term environmental sustainability has gradually become commonly established. As an for example, the Commissioner for Environmental Sustainability of the Australian State of Victoria, P. Sutton, defined environmental sustainability as "the ability to maintain the qualities that are valued in the physical environment" (Sutton, 2004). The Environmental Sustainability Program of the U.S. National Science Foundation for 2009 supports engineering research with the goal of promoting sustainably engineered systems that support human well-being and that are also accordingly compatible with sustaining natural systems.

One of the new journals explicitly focuses on environmental sustainability: Current Opinion in Environmental Sustainability is the first scholarly journal reviewing and synthesizing research on sustainability and environmental change. It provides its audience with a new vehicle to provide timely updates on science and the research programs. It focuses on six areas:

- Climate systems (covering climate and climate change, climate risk management, mitigation and adaptation).
- Human settlements and habitats (covering cities, urbanization and transport).
- Energy systems (covering energy use, energy conservation, renewable energy, energy efficiency and bioenergy).
- Terrestrial systems (covering natural and managed ecosystems, forestry, food systems, biodiversity and ecosystem services).
- Carbon and nitrogen cycles (covering sources and sinks, feedback processes and links to other systems).
- Aquatic systems (covering marine and fresh water ecosystems, fisheries, currents and biodiversity).

An important contribution to the concept of environmental sustainability was made by the OECD Environmental Strategy for the First Decade of the 21st Century (OECD, 2001). The Strategy defines four specific criteria for environmental sustainability: regeneration (renewable resources shall be used efficiently and their use shall not be permitted to exceed their long-term rates of natural regeneration), substitutability (non-renewable resources shall be used efficiently and their use limited to levels which can be offset by substitution with renewable resources or other forms of capital), assimilation (releases of hazardous or polluting substances into the environment shall not exceed their assimilative capacity) and avoiding irreversibility. It identifies five inter-linked objectives for enhancing cost-effective and operational environmental policies in the context of sustainable development:

- maintaining the integrity of ecosystems through the efficient management of natural resources
- de-coupling environmental pressures from economic growth
- improving information for decision-making: measuring progress through indicators
- the social and environmental interface: enhancing quality of life
- global environmental interdependence: improving governance and co-operation.

To enlarge the list of the basic principles of environmental sustainability (without pretending it is fully comprehensive), we may further add (Moldan, 2009):

- long-term perspective (without any designated time limit);
- understanding of the non-linear evolution of complex systems (tipping points, thresholds, sudden unpredictable changes);
- taking feedbacks into account (in particular the positive ones);
- regard for different scales (in time and space);
- flexibility (the ability to react to a changing situation, learning by doing);
- key importance of local conditions; and
- respect for living nature in general and for biological diversity in particular.

Further development of the concept was aided by the Millennium Ecosystem Assessment Project. Although The Synthesis Report (Millennium Ecosystem Assessment, 2005) does not use the term environmental sustainability, it contributes substantially to its elucidation. It identifies ecosystem services and recognizes four categories: provisioning (food, freshwater, wood and fiber, fuel, etc.), regulatory (climate regulation, flood regulation, disease regulation, water purification, etc.), cultural (aesthetic, spiritual, educational, recreational, etc.), supporting (nutrient cycling, soil formation, primary production, etc.). The idea of ecosystem services can be broadened by services provided by global life-supporting systems (such as the stratospheric ozone layer, climatic system, hydrological cycle, and global biogeochemical cycles), by goods provided by the geosphere (mineral resources) and by three-dimensional open space: land on the Earth's surface and the space beneath and above it. To use the term coined by Daily, we may call all these goods and services nature's services (Daily, 1997).

The ecosystem and nature's services are jointly linked to human well-being because it depends on them. To secure well-being, it is essential to maintain the ecosystem and nature's services at an appropriate standard. In other words, environmental sustainability may be defined as maintaining nature's services at a suitable level. Pointing out the indivisible connection between these services and human well-being, and indicating the many concrete expressions of this relationship is the fundamental contribution of the Millennium Ecosystem Assessment Project.

To maintain the adequate quality of nature's services entails care for the systems providing the services: ecosystems and global life-supporting systems that may be called environmental infrastructure. The supply of necessary services is only possible if global ecological systems are in a healthy state. Concern for goods and services provided by nature means concern for nature itself, i.e. for global ecosystems and for biodiversity. Biological diversity is the most important element of environmental infrastructure and an overarching prerequisite for most of the services.

During the years after its introduction in the 1980s, the idea of sustainable development evolved from its rather fuzzy original notion to more precise specifications covering its fundamental pillars. Many important definitions are now presented in quantitative terms using different indicators. The need for a comprehensive analysis of indicators is thus obvious.

2. Indicators

Indicators are popular for establishing league tables. The examples do not pertain exclusively to competitive sports results, but the ranking spirit has been applied to a host of other opportunities: university rankings, the best city to live in, the best hospital, highest crime occurrence, etc. Also, many highly aggregated indicators, indices – e.g. the Human Development Index or the Happy Planet Index – have provided a quick comparison of countries based on such ranking. League tables have their supporters (since the naming and faming/or shaming/principle may be an effective coercive tool) as well as critics (the ranking alone does not say much about sustainability).

Once sustainable development indicators are defined they have to be "measured" in a wide sense, by both quantitative and qualitative techniques. More and more often, availability of data, i.e. obtaining the value of sustainability indicators, is not a problem. The main difficulties relate to selection, interpretation and the use of indicators.

In terms of interpretation, if the indicators are applied over a period of time, they can be used to determine a trend. Although absolute values may not entirely matter, we need a notion of what is acceptable. Thus, the most attractive idea remains having a numeric value for sustainability. That reference value then gives the indicator meaning and distinguishes it from raw data (Gallopin, 1997).

The simplest reference point is a baseline. Baselines are starting points for measuring change from a certain state or date. (ten Brink, 2007). They are common practice and broadly accepted in such fields as medicine, economics, environmental quality, climate change or education. One's health is assessed by comparing actual values, e.g. blood pressure or blood sugar level, to baseline values corresponding to their gender, height, weight and age. In the quality assessment of soil, water and air, and on climate change, pre-industrial background values play a prominent role. In all quality assessments baselines are involved, implicitly or explicitly, and are the dimension according to which the indicator assesses the subject in question. A baseline is thus not a targeted state: the target is set when policymakers agree upon a specific target(s) for an issue.

A meaningful reference value, a target, to measure distance from a baseline may be a background value, standard or norm, or it can be a threshold value for something like irreversibility or the instability of a system (Rickard et al., 2007). The hard targets are set through political processes and thus become important policy drivers, while the soft targets, are based on our notion or knowledge of the limits involved. They use concepts such as sustainable reference values (e.g. sustainable yield), carrying capacity, critical load or minimum viable population. While the choice of hard targets is normative and politically challenging, the setting of soft targets is associated with scientific debate and differing opinions. The existence of a target is of key importance, regardless of the type of target. Even a vague, qualitative target (e.g. reduce the dependency on imported energy resources. . .) may be an important policy driver stimulating both research and policy debate on the desirable state of the issue to be achieved. The benefit of specific, quantitative, time bound targets is then straightforward: The indicators can be linked to them and interpreted clearly on a distance-to-target basis.

The notion of a reference value has even guided an indicator typology developed by the European Environmental Agency (EEA, 1999). It classified indicators into four groups which address the following questions: (1) What is happening to the environment and to humans? (2) Does it matter? (3) Are we improving? and (4) Are we on the whole better off? Indicators form the second group – the performance indicators – comparing actual conditions with a specific set of reference conditions. They measure the 'distance(s)' between the current environmental situation and the desired situation, the target ('distance to target' assessment). Performance indicators are very relevant if specific groups or institutions are to be held accountable for changes in environmental conditions. These performance indicators may refer to different kinds of reference conditions/values, such as national or international policy targets, accepted by governments, and tentative approximations of sustainability levels.

2.1. *Is it acceptable?*

The EEA (1999) has called the above hard targets Policy Target Values (PTVs). They rarely reflect pure sustainability considerations, as they are, by definition, compromises reached through national or international negotiations. The most frequently used concepts of environmental sustainability have been discussed and used in this term over time by international organizations (e.g. IUCN, UNCED, OECD, EUROSTAT and WB). It shows the close ties between environmental sustainability and international or national political or policy oriented initiatives. Some of those set concrete goals and objectives that have to be reached within a certain timeframe (e.g. improving the quality of life of the poor, reduction of industrial pollution, waste recycling). Policy makers and the general public would like to be informed about the observance of the designated goals and objectives. Here, the indicators that exploit the quantitative expression of various aspects of environmental sustainability become involved. If quantification is possible in one way or another, the applicability for achieving the goal of environmental sustainability is rather straightforward.

There has been an abundance of targets of all types for various phenomena from the environmental sustainability domain. Even for experts, it is difficult to keep track of all regulations and their specific terminology. Therefore, there have been initiatives to simplify both access and understanding of these issues, such as the EEAĭs STAR Portal, an inventory of PTVs and SRVs (Sustainable reference values) (EEA, 1999), or a relational database system that captures the semantics of a broad collection of regulations and supports non-expert users in querying the limits database (Kramer and Spandl, 1994). To analyze and elucidate the role of targets, we have focused on selected sets of indicators developed and used by influential intergovernmental organizations – indicators for the UN Millennium Development Goals and Eurostatĭs Sustainable Development Indicators.

Target	Indicators for monitoring progress
7 A. To integrate the principles of sustainable development into the national policies and programs and reverse the loss of environment resources.	- Deforestation: Forested area as percentage of land area, 1990 and 2010 - Climate change: CO_2 emissions, 1990 and 2007 - Ozone layer protection: Consumption of all ozone-depleting substances, 1986-2008 and Montreal Protocol's Multilateral Fund replenishment, 1991-2011
7.B. To reduce biodiversity loss. To achieve a significant reduction in the rate of loss by 2010.	- Portion of land area covered by forest - CO_2 emissions, total, per capita and per $1 of GDP (PPP) - Consumption of ozone-depleting substances - Proportion of fish stocks within safe biological limits - Proportion of total water resources used - Proportion of terrestrial and marine areas protected - Proportion of species threatened with extinction
7. C. To halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation.	- Proportion of population using improved drinking water resources - Proportion of population using improved sanitation facilities
7.D. To achieve, by 2020, a significant improvement in the lives of at least 100 million slum dwellers.	- Proportion of urban population living in slums

Fig. 1. Goal No. 7 from the Millennium Declaration.

Source: Adapted from UN (2010).

The Millennium Development Goals (MDGs) are eight global-scale policy goals to be achieved by 2015 that respond to the world's main development challenges. The eight MDGĭs break down into twenty-one quantifiable targets that are measured by sixty indicators. Goal 7 (to ensure environmental sustainability) includes four targets and ten original indicators, plus three indicators we have derived from the MDG 2010 Report (UN, 2010). The indicators provide information about achieving these goals within certain time periods in each country (Fig. 1).

Target 7 D is an example of the strength of quantified information with regard to policy making. When this Target (to improve the lives of 100 million slum dwellers) was endorsed in 2000, experts had underestimated the number of people living in substandard conditions. In 2003, new and improved data sources showed that the target would cover only a fraction, about 10 percent, of the global slum population. Also, the target was set as an absolute number for the world as a whole, which makes it difficult for governments to set meaningful country-specific goals. Thus, the target will require redefinition if it is to elicit serious commitment from national governments and hold them accountable for implementation (UN, 2010).

In connection with the European Union Sustainable Development Strategy (EU, 2006), the European statistical office Eurostat published "2009 Monitoring Report of the EU Sustainable Development Strategy" (Eurostat, 2009). It is to provide an objective, statistical picture of progress every two years towards the goals and objectives of the EU sustainable development strategy. Given these objectives and targets, the report provides an assessment of whether the EU is moving in the right direction. The selected indicators fall into three levels of importance (headline, subtheme and contextual). There are 10 priority areas (economic performance, climate change and energy, sustainable transport, sustainable consumption and production, management of natural resources, public health, social inclusion, demographic changes, global partnership, and good governance); about half of them have indicators directly or indirectly linked to environmental sustainability. In terms of targets, the indicators have been selected against a set of criteria, with one of them requiring that the indicator have a clear and accepted normative interpretation (Ledoux, Mertens and Wolff, 2005). Eurostat has been seeking and applying the proximity to target method in order to ensure the policy relevance of the whole assessment.

Explicit limits and thresholds are, in fact, needed even in analyses that have been designed to include other types of information without the necessity of defining the targets. The OECD has come up with the term "decoupling" and offered a methodology and indicators to measure the decoupling of environmental pressures from economic growth. This indicator is a quotient of environmental pressure divided by an economic variable. The OECD has explored indicators covering a broad spectrum of environmental issues such as climate change, air pollution, water quality, waste disposal, material use and natural resources, while another set of indicators may be used for a decoupling analysis of four specific sectors: energy, transport, agriculture and manufacturing (OECD, 2002; OECD, 2003).

Decoupling occurs when the growth rate of an environmental pressure is less than that of its economic driving force (e.g. GDP) over a given period of time. Decoupling can be either absolute or relative: absolute decoupling occurs when the environmentally relevant variable is stable or decreasing while the economic driving force is growing; relative decoupling occurs when the growth rate of the environmentally relevant variable is positive but less than the growth rate of the economic variable (OECD, 2002). The evidence shows that relative decoupling is often achieved in OECD member countries while absolute decoupling is less common. The decoupling indicators convey a strong message regarding environmental sustainability since they provide a crucial link between the environmental and other pillars, mostly the economic pillar. Their focus on environmental pressures is a good choice, as pressures are well defined and easy to measure. However, sustainability-wise the interpretation of these indicators should take into account absolute levels of at least the environmental variable (pressures). In other words, we need some targets to show policy makers if there is a threshold for reduction or a ceiling that allows a further increase in pressures. Unless a particular indicator is related to a threshold (i.e. a limit) of sustainable use, one cannot make the judgment that it shows sufficient relative or absolute decoupling to support the conclusion that more sustainable patterns of consumption and production have been achieved (CEM, 2006).

In both sets of SDIs above the targets have important role: they provide a value-based framework for assessment. As external reference values, they stay to the side and are not inserted into the indicator methodology. There may be one final target or a series of interim targets when stricter targets have to be met over a period of time.

Another approach has sought to integrate the target values directly into the algorithm of the indicator calculation. That is the case of Prescott-Allenǐs Wellbeing Index (Prescott-Allen, 2001) or the better known and more recent Environmental Performance Index (EPI), which is very close to the concept of environmental sustainability. It quantifies and numerically benchmarks the environmental performance of a country's policies. It was developed by Yale University and Columbia University in collaboration with the World Economic Forum and the Joint Research Centre of the European Commission (Emerson et al., 2010). The EPI focuses on two overarching environmental objectives: reducing environmental stresses on human health and promoting ecosystem vitality and sound natural resource management. These goals reflect the policy priorities of environmental authorities around the world as well as the environmental dimension of MDGs. The quantitative metrics underlying the EPI encompasses twenty five indicators pertaining to the two objectives above and six policy categories (climate change, productive natural resources, biodiversity and habitat, water, air pollution, environmental health). The authors linked each indicator to a long-term public health or ecosystem sustainability target. For each country and each indicator, a proximity-to-target value was calculated based on the gap between a country's current results and the policy target. These targets are drawn from four sources: (1) treaties or other internationally agreed goals; (2) standards set by international organizations; (3) leading national regulatory requirements and (4) expert judgment based on the prevailing scientific consensus. Fig. 2 shows targets for indicators of selected EPI components (Environmental Health and Ecosystem Vitality objectives).

When possible, targets are based on international treaties and agreements. For issues with no international agreements, targets are derived from environmental and public health standards devel-

Index	Objectives	Policy categories	Indicators	Data sources	Target
EPI	Environmental health (50 %)	Environmental burden of disease (25 %)	Environmental burden of disease (25 %)	WHO	10 DALYs per 1000 population
		Air pollution (effects on humans) (12.5 %)	Indoor air pollution (6.3 %)	World Development Indicators	0 % population using solid fuels
			Outdoor air pollution (6.3 %) (urban particulates)	World Development Indicators	20 µg/m^3 of PM_{10}
		Water (effects on humans) (12.5 %)	Access to water (6.3 %)	World Development Indicators	100 % population without access
			Access to sanitation (6.3 %)	World Development Indicators	100 % population with access
	Ecosystem vitality	Air pollution (effects on ecosystems) (4.2 %)	SO_2 emissions per populated land area (2.1 %)	EDGAR, UNFCCC, REAS	0.01 Gg SO_2/sq km
			NOx emissions per populated land area (0.7 %)	EDGAR, UNFCCC, REAS	0.01 Gg NO_x/sq km
			Non-methane volatile organic compound emissions per populated land area (0.7 %)	EDGAR, UNFCCC, REAS	0.01 Gg NMVOC/sq km
			Ecosystem ozone (0.7 %)	Model for ozone and related	0 ppb exceedance above 3000 AOT40.
				chemical tracers (Mozart II)	

Note: EDGAR denotes Emissions Database for Global Atmospheric Research;
UNFCCC denotes UN Framework Convention on Climate Change;
REAS denotes Regional Emissions Inventory in Asia.

Fig. 2. Environmental Performance Index – components, weights (as % of total EPI score) and targets. Note: EDGAR denotes Emissions Database for Global Atmospheric Research; UNFCCC denotes UN Framework Convention on Climate Change; REAS denotes Regional Emissions Inventory in Asia.
Source: Emerson et al. (2010).

oped by international organizations and national governments, the scientific literature, and expert opinion. Where targets could not be established based on any scientific criteria, sufficiently ambitious targets were formulated by the authors where all countries have some room for improvement. In some cases, they may also represent an ideal state, such as zero percent of the population exposed to indoor air pollution. Other targets such as ten percent of national territory under protected areas recommended by the Convention on Biological Diversity, represent political compromises. It is obvious that such targets do not necessarily reflect the environmental performance required for achieving sustainability. The overall EPI ranking does not tell us which country is actually on a sustainable path, but it provides a sense of which countries are doing best in terms of reaching common environmental targets.

2.2. Is it sustainable?

One of the latest influential reports (Stieglitz et al., 2009) resolutely states that humans ultimately need an assessment of how far they are from sustainable targets. However, despite growing demand from the policy side and the scientific consensus, up to now only a very limited experience exists with indicators that relate environmental quality to target levels created from the perspective of sustainable development (Sustainable Reference Values, SRVs). Recent discussions about environmental limits and thresholds date back to the late eighteenth century. Malthus considered the limits in population growth and an insufficient food supply: population increases in a geometric ratio while means of subsistence increase in an arithmetic ratio (Smith, 1951). Meadows et al. (1972) stimulated discussion of resource constraints worldwide by the publication of "Limits to Growth", arguing that in a finite world economic expansion could not be sustained indefinitely. Most recent notions of limits have been framed around the ideas of footprints and sustainable patterns of consumption and production, both of which imply that there are limits beyond which certain types of growth and development are not sustainable (CEM, 2006).

A widely used methodology, the Material Flow Analysis (MFA), has until now provided useful indicators mostly based on benchmarking, trend analysis and decoupling (Kovanda and Hak, 2008). What is required now is to move to the next stage of setting absolute targets for resource inputs and waste outputs related to those flows. Setting economy-wide resource use targets inevitably involves some degree of normative judgment, such as the principle of international per capita equity in environmental consumption. Normative judgments are both useful and necessary alongside waste assimilation thresholds as a basis for deriving guidance for resource use limits (DEFRA, 2005).

Holdren, Daily and Ehrlich (1995) advocate such a regulative approach towards securing sustainability conditions that:

1. Limit levels of harm to those that are tolerable on a consistent basis (i.e. levels that are non-cumulative) in return for the benefits of the activity that causes such harm;
2. Limit the degradation of only environmental stocks of "essential" resources that can be monitored, to not more than 10 per cent per century, which is 0.1 per cent per year in order to give societies the time to develop substitutes and alter related systems. Current degradation rates are thought to be in the range of 100 per cent or more per century.

Sustainable consumption and production (SCP) is a typical theme where discussions of limits to physical resource use and the scale of the human economy have largely been developed in ecological economics literature from the 1970s onwards. Also, most countries have been developing their SCP action plans with assessment tools – indicators – and the academic discussions has taken on a pragmatic policy-making style involving many stakeholders (ETC/SCP, 2011). One of the key points made during the consultation stage before publication of the SCP framework in the UK was that the indicators needed to provide clearer guidance on progress towards sustainability by linking them to ecological limits or long term targets.

Besides the normative approaches, other attempts to conceptualize sustainable resource management was initially developed and quantified in the early 1990s based on the idea of 'carrying capacity' (Daily and Ehrlich, 1996). The term has been widely used to express the idea that some biophysical limit to resource use might exist. The Ecological Footprint (EF) indicator based on per capita area measures was developed by Wackernagel and Rees (1995). It calculates the amount of biologically productive land and water area required to support a given population at its current level of consumption. It has been further developed most recently by the Ecological Footprint Network and WWF to argue that the results, regardless all conceptual deficiencies, are well-known and straightforward: While 1.8 global hectares per person are available world-wide, Europeans use 4.9 global hectares per person, North Americans use twice that amount, and over a billion Indians use 0.9 global hectares per person. Given present and projected levels of consumption and production there is a risk of the collapse of human welfare by 2030 (WWF, 2010).

Recently, the concept of planetary boundaries has been introduced by the team of Johan Rockström from the Stockholm Resilience Centre, Stockholm University (Rockström et al., 2009). These boundaries define the safe operating area for humanity with respect to the Earth system and are associated with the planet's biophysical subsystems or processes. It is based on the knowledge that the Earth's subsystems react in a nonlinear and often abrupt way, and are particularly sensitive around the threshold levels of certain key variables. Most of these thresholds can be defined by a critical value for one or more control variables, such as carbon dioxide concentration. Not all processes or subsystems on Earth have well-defined thresholds, and at the same time human actions that undermine the resilience of a certain process or subsystems can increase the risk that thresholds will also be crossed in other processes. The authors identified nine processes and associated thresholds which, if crossed, could generate unacceptable environmental change: climate change, rate of biodiversity loss (terrestrial and marine), interference with the nitrogen and phosphorus cycles, stratospheric ozone depletion, ocean acidification, global freshwater use, change in land use, chemical pollution, and atmospheric aerosol loading. The planetary boundaries are values for control variables that are either at a 'safe' distance from thresholds – for processes with evidence of threshold behavior – or at dangerous levels for processes without evidence of thresholds. Unlike thresholds themselves, determining a safe distance involves normative judgments of how societies choose to deal with risk and uncertainty. Based on the baseline values and the safe distance principle, the authors infer that humanity may soon be approaching the boundaries for global freshwater use, change in land use, ocean acidification and interference with the global phosphorous cycle, while three of the Earth-system processes – climate change, rate of biodiversity loss and interference with the nitrogen cycle – have already transgressed their boundaries (Fig. 3).

3. Examples of environmental sustainability indicators in use

3.1. The EU 20–20–20 target

Here we see an important example of the successful application of the concept of environmental sustainability. The leading principle of the EU approach is the "20–20–20 target" approved

Earth-system process	Parameters	Proposed boundaries	Current status	Pre-industrial value
Climate change	(i) Atmospheric CO2 concentration (ppmv)	350	387	280
	(ii) Change in radiative forcing (W/sq m)	1	1.5	0
Rate of biodiversity loss	Extinction rate (number of species per mil. species per year)	10	□ 100	0.1-1
Nitrogen cycle (part of a boundary with the phosphorus cycle	Amount of N_2 removed from the atmosphere for human use (mil. of tonnes per year)	35	121	0

Fig. 3. The overstepped planetary boundaries of the Earth-system processes.

Source: Rockström et al. (2009).

at the Spring European Council in 2007: a 20 percent reduction of greenhouse gases emissions, a 20 percent share of renewable energy resources and a 20 percent rise in energy efficiency, with all three to be delivered by 2020 (EC, 2007). The target has been successively implemented by a series of legal actions within the so-called climate-energy package. The title of the package points to the close connection between the environmental and economic aspects of the issue is an illustration of the notion of environmental sustainability as protection vital to nature's services within the broader concept of sustainable development. The cited 20–20–20 target (as well as the Kyoto Protocol targets) shows that the selected indicators and their numbers when set by a public political process have an important practical value by clearly focusing policies within a given area. The practical steps taken by many stakeholders are influenced by these targets that have far-reaching ramifications in a great number of economic and other sectors. The selection and definition of pertinent indicators to a large extent defines the whole issue.

3.2. Bio-fuels promotion and regulation: the EU approach

This example is related to the issue of bio-fuels. Once hailed as an all-important contribution to environmental improvement in general and climate change mitigation in particular, it has gradually become a highly controversial issue (competition for land with food production, negative impact on biodiversity, minimal or even negative contribution to mitigation efforts and others). In an attempt to solve the controversy, the European Union proposed a new directive on the promotion of the use of energy from renewable sources (adopted by European Parliament in December 2008, and by the European Council in April 2009). Four sustainability criteria were articulated (EC, 2009):

- A general prohibition on the use of biomass from land converted from forest, other high carbon stock areas and highly biodiverse areas;
- A common greenhouse gas calculation methodology which could be used to ensure that minimum greenhouse gas savings from biomass are at least 35% (rising to 50% in 2017 and 60% in 2018 for new installations) compared to the EU's fossil energy mix;
- The differentiation of national support schemes in favor of installations that achieve high energy conversion efficiencies; and
- Monitoring of the origin of biomass.

A set of detailed indicators is given for the concrete implementation of these criteria.

3.3. Measuring, reporting and verification

The role of indicators, namely those focused on the quantification of emissions and their reduction, is evident within the whole framework of the UN Framework Convention on Climate Change – UN FCCC (UN, 1992b). Mitigation efforts are critically important, in particular greenhouse gas emission reduction that is not even imaginable without reliable indicators. The Bali Action Plan, a result of the Conference of the Parties to the UN FCCC in December 2007 (UNFCCC, 2007), highlighted the importance of measurable, reportable and verifiable (MRV) greenhouse gas mitigation actions and commitments. The issue of MRV has become one of the hotly debated issues within the UNFCCC negotiations, which are among the top contemporary global political agendas (Ellis and Moarif, 2009). At the COP 15 in Copenhagen (UNFCCC, 2009) this issue was not resolved. On the other hand, an important agreement was reached at the following COP 16 in Cancun (UNFCCC, 2010).

There are two significant tensions in building a system for monitoring. First, the system needs to be sufficiently uniform to make comparisons between countries meaningful, but it also needs to recognize the significant differences between countries. Second, the system needs to be strong enough to be meaningful, but there is also broad agreement that monitoring should not be punitive. The Cancun agreement strikes a balance in regard to both of these tensions. Both developed and developing countries are charged with creating systems for measurement of emissions reductions. In developing countries, however, only reductions that are supported by international efforts are subject to international measurement and verification. They are subject to international consultation and analysis of their reduction efforts, but only in ways that are "non-intrusive, non-punitive, and respectful of national sovereignty". Developed countries, on the other hand, are to jointly establish a process for international review of their emissions reductions. This is an example of how the issue of indicators directly linked to environmental sustainability is no longer an academic exercise but a critical issue at the highest level of international politics and talks.

4. Conclusions

Environmental sustainability is a concept based on a notion of ecosystem services – both renewable and non-renewable resources and waste absorptive capacity that provide benefits to humans and thus improve their welfare. In order to enjoy and use the services throughout the ages, humanity must learn to live within the limitations of the biophysical environment. The discussion of environmental limits leads us to the edge of what traditional science may provide. Often, scientists and experts provide knowledge of what consequences might follow if certain limits are crossed, although the significance of such limits has to be determined by society at large. A discussion of limits requires us to think about their implications in ways that transcend traditional disciplinary boundaries (CEM, 2006).

But before thinking of the potential impact of human activities, we need reliable information on both activities and limits. Over the past decades, plenty of various indicators and environmental sustainability targets have been developed, tested and suggested for use. Despite a growing demand from the policy side, however, only very limited experience exists with indicators that relate environmental quality to target levels created from the perspective of sustainable development. We argue that based on theoretical findings and some successful examples from real policy making, sustainability indicators should be linked to some reference values and targets. Environmental sustainability, unlike the economic or social spheres, seems to be open for developing and using targets that are firmly rooted in the biophysical properties of the system. Scaling is an important issue here. Environmental limits represent a nested set of rather different constraints at the local through global levels (Dahl, 1999). At the local level, the challenge is to maintain the necessary quantity and quality of environmental resources that the community depends on. At the national level, the variety and diversity of local situations means that some additional factors relevant to sustainability must be considered. It is usually at the national level that some solidarity is expressed between areas well endowed with resources and those that have more limited resources, face difficult conditions, or suffer calamities or disasters. The sustainability of the whole depends on mutual assistance and reciprocity among the parts. At the same time, nations are able to achieve economies of scale in certain functions, services and economic activities. At both the national and local levels, environmental limits are not very fixed because there is always the possibility to call for outside assistance, or to go elsewhere if conditions are truly unliveable. As shown above, it is the planetary level where the environmental limits to development have now become quite evident. For generations, the world seemed so large as to be inexhaustible, but between our population growth and the scale with which science and technology have multiplied our impacts, planetary limits or boundaries suddenly seem very near or have already been overstepped.

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