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An Exploration of Sustainability and its Application to Corporate Reporting

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Abstract:
Regardless of one's view on how sustainability should be defined, there is no denying that the number of initiatives, metrics, organizations and nations working towards its goals has grown exponentially over the last thirty years. This report seeks to cast a wide net in exploring the broad concept of sustainability. In doing so, it emphasizes the exploration of ideas from ecology and ecosystems, which can provide a potent metaphor for sustainability, because ecosystems are arguably inherently abundant, resilient and able to manage uncertainty. The goal of this report is to serve those working to improve corporate sustainability reporting, but not primarily by focusing on metrics or issues already developed in this field. Rather by exploring how academics and practitioners are developing sustainability concepts and tools in *other* fields, it hopes to inspire and seed new ideas and possible approaches to this substantial challenge.

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Executive Summary

Twenty-five years after the United Nations' Brundtland Commission defined sustainable development as the ability "to ensure that the needs of the present are met without compromising the ability of future generations to meet their own needs," the debate around the meaning of sustainability has not been settled. Although the Johannesburg World Summit in 2002 proposed the three-pillar vision for sustainable development that balanced "economic," "environmental" and "social" concerns that has become the current default framework for understanding sustainability, the Rio+20 United Nations Conference on Sustainable Development in 2012 felt the need to call for a clearer definition of the concept and for a new vision for a sustainable future.

A look back over the last century shows how deep the roots of the sustainability debate reach and how often we have struggled to formulate a common vision of sustainable living. We have set off on this path many times before, developing strongly divergent views on what sustainability means. On one end of the spectrum stand those who link the concept of sustainability to requirements for living within our ecological carrying capacity, which imply limits to growth. On the opposite end are those who consider development and economic growth, conducted with minimal impact, necessary prerequisites for a sustainable society in the future. In between, an incredible range of everyday uses and abuses of the word "sustainable" adds further complexity and confusion.

Regardless of one's definition of sustainability, there is no denying that a tremendous growth in the number of initiatives, metrics, organizations and nations working towards its goal has taken place over the last three decades. Behind this momentum in research and practice lie promising new trends. One is to temper neoclassical economists' leading role in conceptualizing the next world order with a variety of sustainability-oriented academic disciplines, such as ecological economics, industrial ecology and sustainability science that can help guide alternative future visions. These disciplines often embrace a "strong sustainability" approach that views natural capital as not being able to be freely substituted for by other forms of capital. These disciplines draw on a range of scientific approaches from biology and ecology to thermodynamics and complex-systems studies to offer new models of sustainability. Another trend is the growing call to move the measurement of progress and sustainability away from measurements solely focused on material-, production- and consumption-flow indicators in society (such as those currently used in calculating national Gross Domestic Products) and to focus instead on a balance-sheet, capital-stock (be it natural, human or manufactured), wealth-preservation approach to building a just and sustainable society.

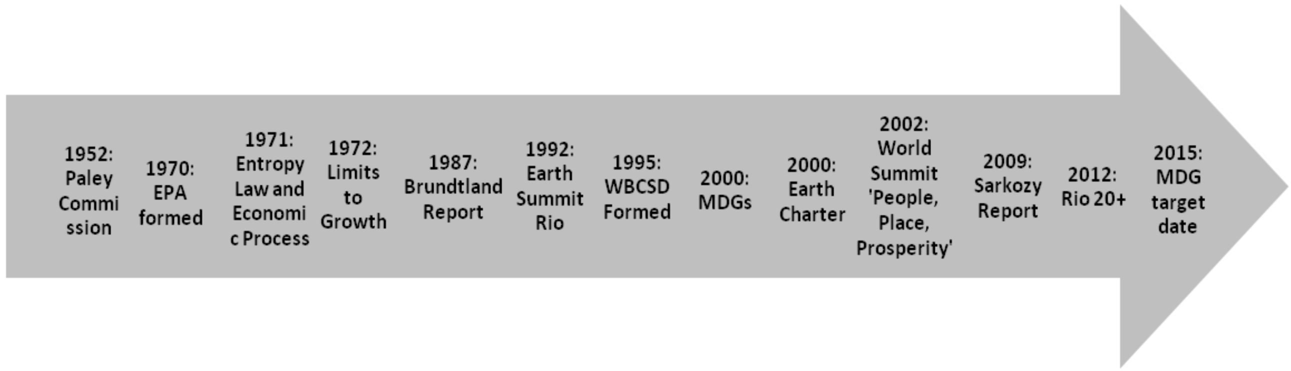
This paper casts a wide net in its exploration of the concept of sustainability. It emphasizes ideas from the study of ecology and ecosystems because, as metaphors for sustainability, natural systems can be viewed as inherently abundant, resilient and able to manage uncertainty. In doing so, we by no means discount the importance of poverty, social justice and community empowerment in a holistic view of sustainability. The ecological concepts

explored in this report can inform and deepen our understanding of these issues that are raised in confronting the challenges of community-oriented, societal sustainability.

If successful in its goals, this report will help those working to improve corporate sustainability reporting not by focusing on specific metrics already in use, but by exploring how academics and practitioners have developed sustainability concepts and tools in *other* fields. In doing so, we hope to inspire and seed new ideas and possibilities for those tirelessly working to improve corporate sustainability reporting and performance.

A Short History of Sustainability

Brief Timeline of Important Sustainability Events



Origins and Originators

Academic and public discussions around the broad concept of sustainability, and all it entails, have been building now for over a century. Divergent narratives around the broad concept of sustainability have emerged, ones that include the concept of economic growth as a key component and others that do not. Those narratives now seem to be converging, as many in society look to leave behind old models and ways of thinking and move toward new approaches that address environmental and social issues more holistically. The following is an overview of individuals and events that have played a role in shaping the current view of the social, environmental and economic elements of sustainability and sustainable development.

Early in the 1900's two economists planted the seeds of the concept. Arthur C. Pigou, a colleague of John Maynard Keynes, developed the concept and theory behind externalities in the 1920's.[1] Shortly afterward, statistician Harold Hotelling applied economic theory to the study of the optimal approach to the extraction of non-renewable resources, using a discount rate and assuming that resources were inexhaustible.[2] After World War II, the environment came into focus with the advent of the nuclear bomb, as the public was becoming aware of issues such as radioactive isotopes appearing in food and the movement of pollution through ecosystems and food-chains. The post-war period also saw the establishment of the United Nations. Governments adopted the Universal Declaration of Human Rights in 1948 in an attempt to strengthen the international legal frameworks in which business was conducted.

Efforts were made to better comprehend environmental and resource constraints in 1952 with the establishment of the U.S. President's Materials Policy Commission, more commonly known as the Paley Commission, after its chairman, William Paley. One of William Paley's legacies was also establishing one of the first natural resource and environmental think-tanks in the U.S., Resources for the Future.[3,4] The Paley

Commission report concluded that resource and energy shortages were inevitable and recommended investing heavily in renewable energy capabilities including solar, wind and biomass. The report was controversial in part because it was released during the Cold War with its focus on building Western economic strength vis-à-vis that of the Soviet Union. Also in the 1950s, geoscientist M.K. Hubbert coined the term “peak oil,” referring to the point when oil extraction will cease increasing. The concept of peak production of natural resources remains debated today, and is now more broadly applied to other resources such as water.[5]

Environmental awareness continued to grow in the 1960s. Rachel Carson’s seminal book *Silent Spring*, which described the impact of pesticides on birds and other animals, had a major impact on environmental awareness.[6] In 1968 Aurelio Peccei, an Italian businessman with ambitions for global economic development planning founded the Club of Rome, an organization of approximately 160 economists. Peccei partnered with Jay Forrester, a computer scientist from MIT, to run computer-assisted structural models of technical, social and biological activities which eventually led to the publication of *Limits to Growth* in 1972.[7] This book catalyzed thinking about environmental and social problems on a global scale. Recent research published in the *Smithsonian Magazine* has validated the patterns of the book’s predictions to date and reignited speculation that natural and economic systems could be headed for collapse.[8] (See Appendix A for details and graphical comparisons.)

In 1971, mathematician and economist Nicolas Georgescu-Roegen published *The Entropy Law and the Economic Process* which likewise emphasized the risks of economic growth.[9] After the publication of *Limits to Growth*, the Club of Rome and Georgescu-Roegen diverged in their research and recommendations. Between 1972 and 1980 the Club of Rome published ten new reports, each report drifting further away from the first report’s concern with material limits to growth according to Georgescu-Roegen. He viewed his role as an academic to be ‘brutally honest’ and continued to warn of the dangers of economic expansion. His frustrations with the Club of Rome led to his resignation from the group.

> After the report of the Meadows Group, (Limits to Growth) the Club began dancing around the computers instead of moving in force to take the banners against the production of armaments, against luxurious waste of natural resources by developed economies, against the dreadful inequalities of nations.[10,11]

Georgescu-Roegen was frustrated in part by approaches attempting to capture realities and qualities of social and biological states using laws that he viewed as essentially mechanical. He termed this tendency of economists to reduce reality to numbers “arithmomorphism.”[12] Meanwhile, in the words of historian Fernando Elichirigoity, the Club of Rome had become an enterprise of “planet management,” looking for technocratic ways to monitor growth—not to constrain it. These academic arguments are important insofar as they underpin the basic divergence in sustainability narratives. Much of Georgescu-Roegen's work formed the foundation of ecological economics and influenced his protégé Herman Daly who is a key contributor to the field and to evolving the concept of sustainability. Echoes of his original work are evident in publications such as the UK Sustainable Development Commission's 2009 publication "Prosperity without Growth? The Transition to a Sustainable Economy."[13]

A handful of other academics raised their voices around this time to challenge the neoclassical economic approach to development. In 1968, Kenneth Boulding, president of The American Economic Association, authored an essay suggesting that the discipline of economics be reconceived with the concept of the finite economy at its core, using the metaphor of a "spaceship earth." He recognized the material and energy constraints of the economy and proposed a shift from the expansionist and limitless resource-world of the "cowboy economy" to the conservative and self-contained "spaceman economy."[14] Production and consumption, cornerstones of the classical economic model, should be removed from their central position and replaced with a capital stock preservation model. Ernst "Fritz" Schumacher's influential publications *Small is Beautiful* and *Buddhist Economics* also challenged neoclassical economic assumptions and instead proposed an economic model grounded in sufficiency rather than the multiplication of wants.[15]

The United Nations – A Major Driver in the Evolution of the Concept of Sustainability

In 1972 at the UN Conference on the Human Environment in Stockholm, the United Nations Environment Program (UNEP) was established with the express purpose of promoting economic development while preserving the environment. It wasn't until 1987, however, with the publication of "Our Common Future" under the guidance of the then-Prime Minister of Norway, Gro Harlem Brundtland, that the UN effectively reconciled the need for development with environmental protection. Also known as the Brundtland Report, "Our Common Future" was the result of a multi-year UN Commission whose membership was split between developed and developing countries. The Commission ultimately attempted to unify the concepts of environmental protection and economic development around the concept of sustainability, defining sustainable development as:[16]

> the ability to make development sustainable – to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs.[17]

This Brundtland definition has become the default standard definition of sustainable development today, focusing on the theme of intergenerational equity. Advocates of the report view its holistic approach to linking economic and environmental issues as its primary strength.[18] Critics portray the concept of "sustainable development" as an oxymoron, arguing that development cannot be *per se* sustainable and that this definition is too focused on human needs.[19,20] Some have argued that account for the requirements of future generations is an insurmountable challenge when society cannot even formulate a consensus around current needs.[21] Others argue that this definition and many of the policies that followed from it should have instead revolved around the concept of 'biocentrism' which seeks to preserve natural systems due to their inherent value beyond their usefulness to humans. Still others view the concept of sustainable development as a capitulation that implies an acceptance of development-as-usual driven by the interests of big business and pays only lip service to social justice and the protection of nature.[22,23]

Although there is effectively universal agreement that high rates of poverty, hunger, malnutrition and general inequalities inter- and intra-nation are intolerable, there is still disagreement on how to solve these problems. Critics of the linking of sustainability with development assert that national governments can easily chose to focus solely on development as an answer to our global problems, assuming that environmental sustainability will take care of itself as development progresses, with no effort to limit irresponsible consumption and the exhaustion of natural resources.

Despite these criticisms, the Brundtland definition has sparked a global, ongoing dialogue on how to envision the Earth and our place on it. It has catalyzed hundreds of organizations, governments and institutions to form core principles around the concept of sustainability. It has influenced international treaties such as the UN Framework Convention on Climate Change and the Convention on Biological Diversity. Perhaps Robert Kates said it best:

> The concept maintains a creative tension between a few core principles and an openness to reinterpretation and adaption to different social and ecological contexts.[24]

Attention to this definition has overshadowed much of the other visionary work contained in the Brundtland report. For instance, the Commission also saw the need for the creation of a level-playing field for industry through regulations and performance standards in order to achieve sustainable development:

> [T]here are limits to what society can expect industry operating in competition with other industries to do voluntarily. Regulations imposing uniform performance standards are essential to ensure that industry makes the investment necessary to reduce pollution and waste and to enable them to compete on an equal footing."[25]

The Brundtland definition laid the groundwork for the UN Earth Summit in Rio in 1992, with 150 countries and 30,000 individuals in attendance. From this meeting came the creation of 27 principles for sustainable development.[26] (See Appendix B) It also saw the adoption of Agenda 21, a comprehensive plan for sustainable environmental management.[27] During the 1992 UN Earth Summit an attempt was made to create an Earth Charter, a global declaration of sustainability values and principles. This effort did not result in the adoption of a formal UN policy, but did come to fruition independently in the formation of The Earth Charter organization, officially launched in 2000 and now endorsed by over 14,000 individuals and organizations. The Earth Charter identifies four first order principles: 1) respect and care for the community of life, 2) ecological integrity, 3) social and economic justice, and 4) democracy, non-violence and peace.[28]

Some of the business community members attending the 1992 Earth Summit went on to create the World Business Council for Sustainable Development (WBCSD), which was officially formed in 1995 with 48 corporate members. The WBCSD was instrumental in creating and promoting the concept of "eco-efficiency," which it defined as:

> . . . creating more value with less impact. Companies committed to eco-efficiency endeavor to produce goods and services using fewer resources and generating less waste and pollution. [29]

This relatively undemanding concept gained wide acceptance, especially in the 1990's. In the WBCSD's recent "Vision to 2050" publication the concept of eco-efficiency is still used, but accompanied by many other sustainability tools and techniques targeting specific industries.[30]

Addressing the social aspects of sustainability, in 1995 Copenhagen hosted the World Summit for Social Development, which focused on the human dimension of development and drafted ten commitments touching on topics of poverty, education, equity, equality, and the need for full employment.[31]

The UN's 2002 World Summit on Sustainable Development in Johannesburg revolved around the three-pillars of "people, place and prosperity." The focus on the three pillars was seen as an improvement on the Brundtland formulation because it emphasized the fact that development need to account not only for economic or environmental dimensions, but for societal ones as well. The three-pillars model has been integrated into many organizations' vision of sustainable development.

At the turn of the 21st century, the UN Millennium Development Goals were also created through a dialogue between 193 nations and 23 international institutions. These eight broad sustainability goals came with specific targets and indicators, a pragmatic systemic approach with a deadline of 2015 and national progress reports.[32] (See Appendix C for a list of the Millennium Development Goals, targets and indicators.)

In 2011, after five years of research, human-rights and international development specialist, John Ruggie, submitted Guiding Principles for Businesses and Human Rights to the UN, an important first step for the UN in explicitly outlining the expectations of business in the area of human rights.[33] In 2012, the United Nations Sustainable Development Summit in Rio called for specific indicators and targets for sustainable development, including calls for integrating goals such as universal access to information, public participation, access to redress and remedy and environmental justice for the poor and marginalized amongst the other more mainstream social and environmental indicators.[34]

Sustainability Beyond Brundtland and the United Nations

Below are summaries of a number of the major non-UN sustainability initiatives and programs.

Organization for Economic Co-operation and Development (OECD)

Outside the sphere of the United Nations, there has been a mushrooming of organizations working on sustainability and the concept has become ingrained in many governments, multi-national organizations and regulatory bodies. The OECD, for example, promotes the sustainability policy agenda of its member nations by doing regular reviews of member nations' performance. This includes measuring degradation of natural resources and consumption and production patterns. The OECD also conducts key research around topics such as trade patterns, policies, and subsidies that work against achieving sustainability. It has also outlined a set of principles for sustainability in its 2001 "Environmental Strategy Report for the First Decade of the Twenty-first Century." The four principles are based on: Regeneration, Substitutability, Assimilation and Avoiding Irreversibility (see box below).

OECD's Four Environmental Sustainability Principles

I. **Regeneration:** Renewable resources shall be used efficiently and their use shall not be permitted to exceed their long-term rates of natural regeneration.

II. **Substitutability:** Non-renewable resources shall be used efficiently and their use limited to levels which can be offset by substitution by renewable resources or other forms of capital.

III. **Assimilation:** Releases of hazardous or polluting substances to the environment shall not exceed its assimilative capacity; concentrations shall be kept below established critical levels necessary for the protection of human health and the environment. When assimilative capacity is effectively zero (e.g. for hazardous substances that are persistent and/or bio-accumulative), effectively a zero release of such substances is required to avoid their accumulation in the environment.

IV. **Avoiding Irreversibility:** Irreversible adverse effects of human activities on ecosystems and on biogeochemical and hydrological cycles shall be avoided. The natural processes capable of maintaining or restoring the integrity of ecosystems should be safeguarded from adverse impacts of human activities. The differing levels of resilience and carrying capacity of ecosystems must be considered in order to conserve their populations of threatened, endangered and critical species.

Source: "OECD Environmental Strategy for the First Decade of the Twenty–first Century," 2001.

In 2008 the OECD published 'Guidelines for Multinational Enterprises' with the

> . . . aim to ensure that the operations of these enterprises are in harmony with government policies, to strengthen the basis of mutual confidence between enterprises and the societies in which they operate, to help improve the foreign investment climate and to enhance the contribution to sustainable development made by multinational enterprises."[35]

The report listed 11 principles for multinationals as well as guidelines on disclosure of corporate sustainability information including "information on the social, ethical and environmental policies of the enterprise and other codes of conduct to which the company subscribes."[36]

Most recently, the OECD has published its *Environmental Outlook to 2050* in which it stressed that progress on an incremental, piecemeal, business-as-usual basis in the coming decades will not be enough and that there is compelling scientific evidence that we may be nearing tipping points, or biophysical boundaries, beyond which rapid and damaging change becomes irreversible.[37] Likewise, the European Union has evolved target and indicators of Sustainable development with goals of achievement by 2020. (See Appendix D for a full list of the European indicators from this report.)

Sustainability and the US Government

The first major federal environmental law in the US was the National Environmental Policy Act of 1969 (NEPA) declaring a national policy "to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans."[38]

The reference to intergenerational equity precedes the Brundtland report by almost twenty years. The Environmental Protection Agency was officially established the following year in 1970 and throughout the 1970s established laws around protection of air and water and the control of hazardous wastes. Through the 1980s the EPA gained the power to impose liabilities on parties responsible for pollution and to establish a process of remediation. The establishment of a public database monitoring the disposal of industrial chemicals, the Toxics Release Inventory program under the Emergency Planning and Community Right-to-Know Act, was a watershed event for the agency.

Beyond the EPA, the US Department of Interior also has responsibility for sustainability issues such as enforcing the Endangered Species Act and the Surface Mining Act. The US Departments of Transportation, Agriculture, Energy and the US Army Corps of Engineers likewise play important roles. Many of these departments have expansive and conflicting mandates coupled with limited resources which make addressing sustainability issues a challenge.

In 1993 President Clinton created the President's Council on Sustainable Development, which issued its principal report "Sustainable America: A New Consensus for Prosperity, Opportunity, and a Healthy Environment for the Future" in 1996. It noted that "a sustainable United States will have a growing economy that provides equitable opportunities for satisfying livelihoods and a safe, healthy, high quality of life for current and future generations."[39]

The Council lacked political staying power and was disbanded in 1999. More recently another executive-level committee has been established, named the National Science and Technology Council's Committee on the Environment, with the goals of increasing research around the topics of natural resources and sustainability and to help interagency dialogue on these topics. Over 20 federal agencies and departments are involved in the Committee, from the Departments of Agriculture, Commerce, and Defense to the Environmental Protection Agency, NASA, and the Smithsonian Institute.[40]

One other notable effort to understand the concept of sustainability within an American framework was conducted by the Board on Sustainable Development, part of the U.S. National Research Council. Through broad literature searches the Council outlined what advocates and researchers sought to "sustain" and what to "develop" and the relationship between the two. To be "sustained" were nature, life-support and community and to be "developed" were people, economy and society[41]. (See Appendix E for full list.) The Board went on to publish "Our Common Journey," which concluded that it would take no less than two generations to achieve a transition to sustainability (around 2050).[42] William Clark, one of the authors and now the head of the Sustainability Science Program at Harvard, stresses that the core of the sustainability concept is the three-pillar approach of the environment, society and economy and that even though a corporation may have strong sustainability practices in two of the three pillars, if fails in one then the corporation overall cannot be viewed as being on a sustainable path. In addition he stressed that the long-term (meaning keeping one's grandchildren in perspective) needs to be considered.[43]

The EPA has highlighted sustainability in its strategic plan for 2011-2015 with the specific goal of "institutionalizing" the concept.[44] The agency recently convened a committee under the Science and Technology for Sustainability Program (STS) of the National Research Council to provide an operational framework for integrating sustainability into its regulatory framework. STS functions include providing networking platforms for leaders in sustainability and working toward product sustainability certifications.[45] In the STS report titled "Sustainability and the US EPA," one of the key findings is that organizations that most effectively integrate sustainability into their work and culture are those that base their program on clear principles, vision, strategic goals, and implementation process. [46] STS recommended the EPA adopt a broad set of sustainability principles (beyond the narrower present focus on environmental and human health impacts) and specific standardized goals, indicators and metrics (see Table 1). It also recommend evolving additional indicators around environmental justice, children's health, sustainable communities and regional ecosystems such as the Great Lakes.[47]

Table 1: The Report 'Sustainability and the U.S. EPA' (2011) recommended establishing sustainability principles as well as a system of linked goals, indicators and metrics. Summarized from page 43 of report.

Goal	**What is specifically sought to be achieved.** Determined through the use of measured indicators	Example: Reduce mercury emissions from electric utility steam generating units.
Indicator	**Summary measure that provides information on the state of, or the change in a system that is being measured.**	Example: Mass of mercury emitted per heat energy input.
Metric	**The unit of measurement** of how the indicator is being measured.	Example: grams Hg/Kwh – grams mercury per energy input in kilowatt hour.

Defining Sustainability

While multi-lateral organizations and scientific boards have tried to capture the elusive concept of sustainability, a quick query on Google illustrates how widely the term has been used and abused. Google trend analysis of the terms "sustainable," "sustainability" and sustainable development." shows that interest in these concepts has been growing, especially with respect to business and industry. [48] Search terms rising rapidly have been "sustainability jobs," "sustainable food," "energy sustainability" and, aptly, "definition of sustainability" and "what is sustainability."[49]

Almost anything can be labeled or defined as "sustainable"; sustainable communities, sustainable design, sustainable energy, sustainable packaging, sustainable brands, sustainable marketing and sustainable tourism to cite but a few.[50] Critics of the Brundtland definition worried that the concept would be open to "mission-creep." For example, products and services that are seen as more environmentally friendly than average generally would come to be labeled "sustainable." The word "sustainable," for example, appears no less than 80 times in Marks & Spencer's 2011 54-page "How We Do Business."[51] In this report "sustainable" was used in reference to: retailer, business, sourcing, cotton, palm oil, fabrics, farming, packaging materials, wood, fish, life, learning store, sources, tuna, textiles, routes, and practices.

Common elements across definitions of the concept of sustainability are listed below. A broad sampling of sustainability definitions and principles is included in Appendix F.

Common Elements in Definitions of Sustainable Development or Sustainability			
Long-term		**Holistic Approach**	
	Intergenerational equity		**Environmental Justice**
Social, Environmental, Economic Pillars		**Global Scale**	
	Equity		**Interconnected**
Defined Limits		**Systems-based**	
	Complex		**Living within carrying capacity**

Industrial ecologist and author John Ehrenfeld suggests that the best way to understand the holistic and complex nature of sustainability is to first look at the concept of unsustainability.[52] Health and disease are not opposites he argues, as disease can generally be tied to the dysfunction of specific parts of the system whereas health is a property of the whole system. The same is true of unsustainability and sustainability. Unsustainability, that is, the presence of dysfunction in the natural and social worlds, is not merely the opposite face of sustainability. Reducing unsustainability, the objective that is the driving force behind dematerialization, eco-efficiency, and other strategies associated with sustainable development, cannot be assumed to automatically produce sustainability.

The Institute of Sustainability Professionals last year launched a Lexicon Project to clarify the terminology used in their field. The Institute is now working on defining the context, scale, interdisciplinary nature and standards, codes, norms and principles around the concept of sustainability.[53,54] In the absence of a universally accepted definition, practitioners using the term sustainability should define specifically the context in which it is being used and the spatial and temporal parameters for its use. Substituting other terms such as “organic,” ”stable,” ”zero-to-landfill” could also provide a more accurate and meaningful approach.

Measuring Sustainability: Indicators and Indices

Since the Brundtland Report and its broad definition of sustainable development many organizations and initiatives have worked to develop indicators and make sustainability "operational." One such initiative is the Socioeconomic and Data and Application Center (SEDAC), which aggregates geospatial, remote sensing and global databases around the concept of sustainability. In addition to indicators on resource depletion, pollution levels and environmental quality, sourced primarily from North American academic institutions, the center also provides data on sustainability indices such as the Environmental Vulnerability Index, Environmental Performance Index, and the National Footprint Accounts. One particularly interesting metric is the Ecosystem Wellbeing Index, which measures a country's sustainability by weighting environmental assessments alongside human development indicators.[55] Another key indicator gauges Environmental Vulnerability, which reflects the extent to which the natural environment of a country is prone to damage and degradation.[56]

Another large scale global effort in aggregating and disseminating sustainability data is through the United Nations' System of Integrated Environmental and Economic Accounting (SEEA), established in 1995. The SEEA is a subset of the System of National Accounts (SNA), the international standard for tracking and reporting economic activity. The goal of SEEA is to allow environmental statistics to be compared to economic statistics to elucidate patterns of sustainability for production and consumption.

The SEEA comprises four categories of accounts. The first includes purely physical data related to flows of materials. The second is based on those elements of the existing SNA that are relevant to the good management of the environment. The third accounts for environmental assets measured in physical and monetary terms (timber stock accounts, for instance). The fourth deals with how the existing SNA might be adjusted to account (exclusively in monetary terms) for the impact of the economy on the environment. Three sorts of adjustments to these accounts are being considered: those relating to resource depletion, those concerning so-called defensive expenditures (conservation easements, for instance), and those relating to environmental degradation.

Sustainability indicators—their formulation and the decision-making process involved in creating them—is a very active field of research and discourse at present. Multilateral organizations such as the UN and OECD, governments and academics are all actively taking part in the ongoing discussions of how best to "measure the immeasurable." In their book, *Sustainability Indicators: Measuring the Immeasurable?,* Bell and Morse outline many of the most commonly used sustainability indicators and evaluate decision-making models for promoting sustainability within ecosystems.[57] One of the book's reoccurring themes is that it is important to involve as many stakeholders as possible in creating sustainability indicators, especially when evaluating specific projects, and that there are many techniques to manage these stakeholders' expectations. These aspects of stakeholder involvement may have particular applicability for corporations deciding which corporate social responsibility metrics to track and report on. Corporations might, for example, extend the concept to the creation of community and scientific advisory boards as a sustainability resource. Ultimately, attempts to measure sustainability will help improve language, discourse, culture and decision-making when it comes to corporate sustainability management, data gathering and disclosure. (For a summary of these sustainability indicators see Appendix G.)

Major Trends

Summarized below are a few of the contemporary trends in thinking about sustainability, particularly those with relevance for corporate social responsibility reporting.

Move to Strong Sustainability

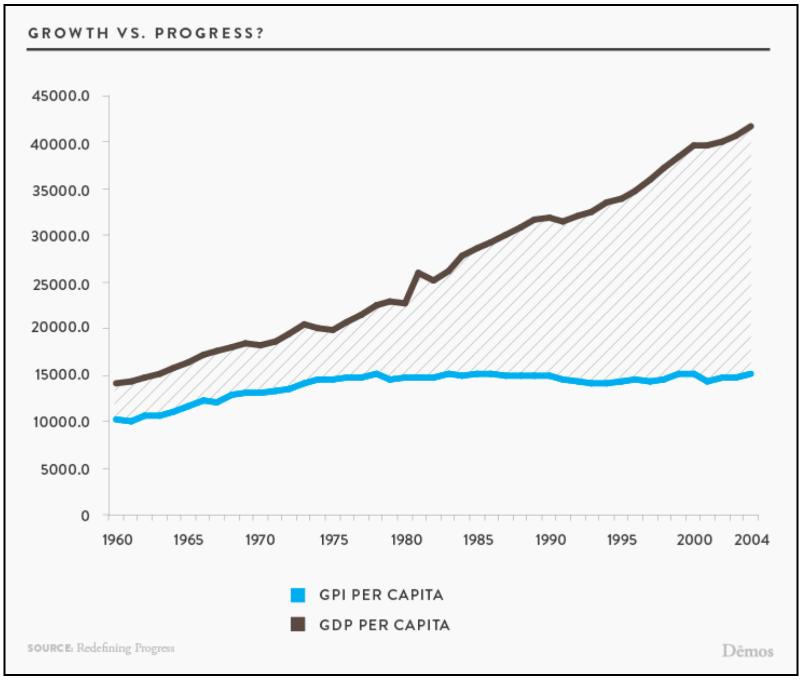
Advocates of a "strong sustainability" viewpoint often see the evolution of the concept of sustainability as having been hijacked by those economists who view the environment as a subset of the economy, with nature being one of many types of capital to draw upon. The terms 'weak' and 'strong' sustainability are often used to describe the role of natural resources in economic modeling. Weak sustainability assumes that any type of capital is perfectly substitutable for natural capital. For example, if a nation exploits all its non-renewable resources but invests all of its profits into education, then the country is no-worse off, it has simply substituted human for natural capital. There has been a trend to move toward a "strong" sustainability point of view in which natural capital is considered intrinsically valuable and truly non-substitutable. Since its 2001 policy paper on sustainable development, the OECD has advocated the exclusive use of the strong sustainability concept.[58]

Capital Stock (Balance Sheet) Approach

One of the most frequently recurring themes across the literature on sustainability is the call to shift economic development away from an income-statement approach and its "flow-variables" such as consumption, production, and through-put of material, towards a focus on a capital-stock, wealth preservation, well-being or a balance-sheet focused approach. Advocates of this viewpoint argue that true well-being is determined by the wealth (be it in resources, social assets or knowledge) that a society possess rather than the speed at which it consumes and processes materials.

Economists William Nordhaus and James Tobin in 1972 were among the first economists to formulate arguments against the exclusive focus on GDP as a measure of wellbeing and proposed the Measured Economic Welfare index (MEW).[59] When research showed that the performance of this index was highly correlated with that of GDP during the period from 1929-1965, economists generally continued to view GDP an adequate proxy for welfare.[60] Twenty years later, ecological economist Herman Daly together with theologian John Cobb updated the performance of the MEW and found that the performance of the MEW fell dramatically relative to the GDP in the latter half of the new time series. They went on to propose another index of Sustainable Economic Welfare (ISEW), which built on the MEW by also accounted for environmental costs.[61] From the ISEW evolved the Genuine Progress Indicator (GPI) which shows how sustainable welfare has diverged from and substantially lagged traditional indicators of development, namely GDP, since 1960 in the United States (Figure 1 below).

Figure 1: Gross Domestic Product versus Gross Progress Indicator for the United States. Source: Redefining Progress via demo.org.



A major report commissioned by French President Sarkozy in 2008, and led by Joseph Stiglitz, Amartya Sen and Jean Paul Fitoussi advocated refocusing economic indicators away from consumption toward indicators of social progress.[62] The authors acknowledged GDP would have an ongoing role as an indicator of economic activity, but warned that using it alone to guide policy could lead to poor decision-making. Over-fixation on GDP, they argued, is a distraction from measuring more relevant indicators of our well-being, such as health, education, physical and economic insecurity, personal activities, political voice and governance, social connectedness, health of our resources and material living standards. They argued that developing a new set of indicators that track well-being and sustainability is important if society is to move forward with a common sustainability agenda.

European political activist Sara Parkin has researched and written extensively on the need to view sustainability from a capital-stock perspective.

> Sustainable development is the process by which, over time, we succeed in managing the different capital flows in our economy on a genuinely sustainable basis. However, according to the scientific principles that underpin sustainability, it is worth noting that there are only two real sources of wealth—that which flows from the resources and

services provided by the Earth (natural capital), and that which flows from our own hands, brains and spirits (human capital).[63]

Parkin's five-capital model for sustainability includes natural capital, human capital, social capital, manufactured capital and financial capital. (For a detailed description of these capitals see Appendix H.) Others have classified capitals differently. In general, however, their definitions encompass natural assets and services and the development of human knowledge and social systems.

Some of those lobbying policy-makers to abandon consumption-oriented models view positively the making of products far more durable, while others such as those in the De-Growth movement advocate far stricter limits on development.[64] Interest in the latter approach is reaching policy-makers through such reports as the UK's recent "Prosperity without Growth."[65]

Order Through Hierarchy

Another development is the development of sustainability hierarchies. Marshall and Toffel have categorized the use of the term sustainability by scholars, policy makers, companies and NGOs into one such hierarchy. [66] (See Appendix I.) Like psychologist Abraham Maslow's Hierarchy of Needs, their hierarchy places the most basic of considerations—the survival of the human race—at the base of the sustainability pyramid, and then proceeds to considerations of health, extinction of species and the violation of human rights as it approaches the top[67]

Manfred Max-Neef proposed a matrix of human needs that are interrelated and interactive that some say improve on Maslow's hierarchy by assuming that different sustainability needs can be pursued simultaneously.[68,69] It would also be possible to construct a sustainability hierarchy that would have as its foundation the preservation of the physical and biological elements of healthy ecosystems, while the second level would be social structures that lend support to the proper functioning of the first. Examples of such social structures would be the establishment of institutions to protect and provide education on physical sustainability or the equitable distribution of access to, and protection of, stocks of natural and social wealth. The third level would be the establishment of practices and institutions that would strive to move towards a more sustainable society.

Rise of Sustainability Science

Another relatively young field coming to the fore is sustainability science with researchers in this field describing it as neither basic nor applied science, but rather as centered on use-inspired basic research.[70] In 2005 the National Academy of Sciences approved a new portal on its website. This field pursues research questions such as: [71]

- How can dynamic interactions be better incorporated into emerging models and conceptualizations that integrate the Earth system, social development and sustainability?

- How are long-term trends in environment and development reshaping nature–society interactions?
- What factors determine the limits of resilience and sources of vulnerability for such interactive systems?
- What systems of incentive structures can most effectively improve social capacity to guide interactions between nature and society toward more sustainable trajectories?
- How can science and technology be more effectively harnessed to address sustainability goals?

Over the past seven years the Proceedings of the National Academy of Sciences (PNAS) has published over 300 papers in its section on sustainability science.[72]

Need to Focus on Scale

Sustainability assessments must incorporate the concept of scale in space and time in order to comprehend the impact of industrial and human activities within ecological and social spheres. In order to understand how well a man-made system such as an economy, industry or corporation is going to function and the resulting impacts it will have on natural life support systems and ecosystem functions, one must use measurements of scale. Over what space is sustainability to be achieved? The spatial scale may correspond to a farm, city, region or the Earth and everything in between. Over what time is sustainability to be achieved? The temporal scale may correspond to a human generation or to the cycling or regeneration capacities of a target ecosystem, which may encompass minutes or hundreds of thousands of years.

A meeting sponsored by the Rockefeller Foundation and the International Institute for Sustainable Development at Bellagio, Italy in 1996 stressed the importance of scale and the allowance for repeated and standardized measurement within ten guiding principles in making sustainability operational.[73] (See Appendix F for the ten Bellagio Principles.) The Bellagio Principles address key issues around measuring sustainability and call for clear definitions, a holistic focus, and an acknowledgement of the importance of time and space in any assessment of sustainability.

A New Constitutionalism

Underlying issues of sustainability and how it links to with corporate reporting is a fundamental question of how knowledge is created, maintained and used by society. Who ultimately should dictate which metrics corporations should report so that society really understands their social and environmental impacts? Understanding agency and location of authority in today's global society involves an intertwining of public and private codes.[74] Legal scholar Gunther Teubner argues that trans-national corporations are literally generating constitutions without a State.

> An autonomous, non-state, non-political, and hence genuinely societal constitutionalization occurs in the codes of transnational corporations, since they

> juridify reflexive social processes that concern the relationship of the company with its environments by linking them to on their part reflexive legal processes, i.e. standardizations of standardizations. Under this condition, it is reasonable to talk of elements of a genuine constitution within the corporate codes of transnational corporations. The codes show indeed typical elements of a constitution: regulations concerning the establishment and practice of organizational decision-making (procedural rules of the corporation) and the definition of the system boundaries (fundamental rights of individuals and institutions vis-à-vis the corporation)." [75]

Who ultimately should dictate how society is structured? Should it be an elected government, guided by a ratified constitution or should it be the shareholders as the owners of the corporation, or global multi-lateral bodies? How do we maximize stakeholder involvement in how we guide the role of corporations? How does society deal with uncertainty? How do we manage and mitigate against risk? Which agents of society should be involved in driving the agenda on corporate sustainability practices going forward and if those fail which should take their place?

Rise of Ecological Economics and Industrial Ecology

Increasingly societies are looking to ecology and its related fields to provide the next tool-kit for addressing sustainability problems. [76] While economists have never been shy about making policy recommendations, ecologists have historically been slow to do so. Natural scientists have tended to hold back from policy discussions for the sake of maintaining objectivity.[77] A few notable exceptions include ecologists H.T. Odum and Herman Daly, who have been at the forefront of applying concepts from ecology to sustainability problems. Along with Georgescu-Roegen's earlier work, they have planted the roots of the field of ecological economics, from which have grown other disciplines such as industrial ecology, social ecology and sustainability science.

A 1982 symposium in Sweden called "Integrating Ecology and Economics" brought together a number of people who would later be instrumental in the field, including Robert Costanza,, Herman Daly, Charles Hall, Ann-Mari Jansson, Bruce Hannon, H.T. Odum, and David Pimentel. From this meeting emerged the *Journal of Ecological Economics* and the International Society for Ecological Economics. The *Journal* sets out its mission as "extending and integrating the study and management of 'nature's household' (ecology) and 'humankind's household (economics)." The three founding positions of the Society and the field of ecological economics are:

- The human economy is embedded in nature, and economic processes are actually biological, physical, and chemical processes and transformations
- Ecological economics is a meeting place for researchers committed to environmental issues

- Ecological economics requires trans-disciplinary work to describe economic processes in relation to physical reality

Industrial Symbiosis

Another important concept in this field is industrial symbiosis, which describes close-knit industrial complexes in which the individual enterprises interchange their wastes and by-products with others. This aspect of industrial ecology emeged after the “discovery” of the symbiotic industrial community of Kalundborg, Denmark, with its interrelated corporations in the power, oil, pharmaceutical, fishing, fertilizer and construction industries.[78] Industrial ecologists have proposed a variety of ways forward for the field.

Industrial Systems Mimicking Ecosystems

Another concept key to industrial ecology is the design of industrial and corporate processes and systems that mimic natural ecosystems. Geophysicist Robert Frosch described this insight.

> The idea of an industrial ecology is based upon a straightforward analogy with natural ecological systems. In nature an ecological system operates through a web of connections in which organisms live and consume each other and each other’s waste. The system has evolved so that the characteristic of communities of living organisms seems to be that nothing that contains available energy or useful material will be lost. There will evolve some organism that will manage to make its living by dealing with any waste product that provides available energy or usable material. Ecologists talk of a food web: an interconnection of uses of both organisms and their wastes. In the industrial context we may think of this as being use of products and waste products. The system structure of a natural ecology and the structure of an industrial system, or an economic system, are extremely similar.[79]

Systems Studies

The interconnectedness of our societies and the ability of the human species to adapt and change with our environment using information and technology add yet another layer of complexity to the field. Sustainability science is beginning to grapple with this complexity, recognizing the importance of a subfield investigating Human-Environment Systems (HES) as complex adaptive systems. Complex Adaptive Systems are composed of agents that interact locally in time and space and then respond to their environments based on information they gather from these interactions. These emergent behaviors are not imposed or predetermined and Complex Adaptive Systems (CAS) are often unpredictable and uncertainty.[80]

The CAS approach to understanding sustainability is seen by some as critical to the uncovering of the underlying structural aspects of sustainability and the development of new agent-based groups. CAS is also useful in understanding the robustness of systems and their capabilities to continue to function in the face of disturbance by balancing rigidity or resistance with flexibility and resiliency.[81]

An example of an HES is a local irrigation system built by farmers to coordinate and control the flow of water and to mitigate risks associated with seasonal variability. The water available in the irrigation system comes from the entire watershed, a far larger spatial scale. The farmers using the irrigation system still remain vulnerable to disturbances by other agents using the watershed upstream, and also through natural ecosystem changes and shocks such as occurrences of 100-year floods or droughts. The National Science Foundation, recognizing the need to understand these types of networks and interconnections has brought together experts in ecology, economics, political science, remote sensing, mathematics, limnology and computer science in its Coupled Human and Natural Systems (CHANS) program (www.chans-net.org), which drives the development of new models and practical applications in this field.

Ecosystems as Inspiration

Ecosystems as described above can serve as a metaphor for sustainability. An ecosystem is a *structural* and *functional* segment of nature consisting of a community of living beings and their physical environment, interacting and exchanging materials among themselves.[82] Ecosystem structure refers to the systematic physical organization of biotic and abiotic components. For example, freshwater wetland structure consists of standing water over saturated and anoxic soils, with a plant community consisting of species adapted to these conditions. Ecosystem function is the capacity of a natural system to provide goods and services that satisfy human needs.[83] Functions tend to fall under four broad areas: regulatory, carrier, production and information functions. Freshwater wetland functions would include water storage and ground water recharge (regulatory function), providing a suitable habitat as a fish nursery (carrier function), processing of heavy metals and organic materials to produce clean water (production function) and picturesque areas for viewing wildlife (aesthetic informative function).

Ecosystems are open systems, with materials and organisms that are constantly entering and leaving. The flow of inputs and outputs is a key concept. Energy is one essential input, with the sun as the most important source, but geothermal or gravitational energy can also be an input. Other essential inputs are water, air and nutrients, which are all necessary for life. Other materials and organisms may enter and leave depending on the nature and location of the ecosystem.

Ecological modelers use five components to understand emergent attributes of ecosystems: properties (states), forces (energy or causal forces that drive the system), flow pathways (energy or material transfers), interactions (forces and properties interact to modify, amplify or control flows), feedback loops (output loops back to influence an upstream component).

Several disciplines look to ecosystems and their emergent properties or operating principles for inspiration. Emergent properties refer to the functional interactions of all the components of a system and cannot be predicted from the study of the components in isolation. Highly resilient and dynamic, with high regenerative and recycling capacities, ecosystems can be considered the ultimate model for sustainability. Among the key emergent properties and principles of ecosystems are: [84,85]

1. Resilience 2. Abundance and Diversity 3. Uncertainty

We now turn to an exploration of a number of key concepts from various fields of study relating to these three emergent properties. The exploration of these three emergent properties is not intended to be exhaustive, but rather representative of unifying concepts in the fields of sustainability science and thinking that might stimulate ideas for the conceptualization of corporate social responsibility when it comes to sustainability measurement and reporting.

System-level Sustainability Principles Applicable to Evaluating Corporations

Ecosystem Principle I: Resilience

Resilience can be measured by the magnitude of disturbances that can be absorbed before a stable system loses its equilibrium. [86,87] Resilient and dynamic ecosystems have multiple steady states. The loss of ecosystem resilience directly impacts human activities through the potential loss of biological productivity and reduced capacity to support human life. It may result in an irreversible loss of ecosystem services. Diversity of organisms and heterogeneity of ecological functions has been suggested as one signal of ecosystem resilience.[88] Below are some examples of characteristics of resilience relevant to sustainability.

❖ **Carrying Capacity**

Carrying capacity is the maximum population size that a particular environment can support with no degradation of the habitat. At carrying capacity there is just enough food and habitat to maintain the existing population and the rate of growth is zero. According to Bell and Morse carrying capacity is the core concept driving the modern view of sustainability.[89] A group of eleven prominent ecologists in 1995 published a policy forum letter,[90] arguing that the view of economic growth as being good for the environment is fundamentally flawed. Many economists at the time were using Kuzenet Curve models to illustrate environmental improvement beyond a certain per capita income threshold.

The theory that environmental degradation drops with economic growth, they argued is unsound for four main reasons. First, the relationship may hold for pollutants that carry high short-term costs such as fecal coliform and sulfur in water, but it does not account for the *accumulation* of stocks of waste, which often increase with a function of income.[91] The accumulation of carbon dioxide in the atmosphere from high fossil fuel consumption in developed countries is a classic example. Second, it is imperative to look beyond simple pollution levels relative to economic growth, and take into account resource stocks in total, such as stocks of forests and soil cover. Third, although pollutants may decline in one country this may involve increasing pollutants in another as the nation shifts toward a service economy and industrial production is outsourced.[92] Fourth, in most cases when emissions have declined with rising incomes, reductions were due to institutional reforms and legislation, but these reforms often ignore international and intergenerational consequences. Ultimately the authors defined environmental sustainability as ecosystem resilience, and proposed that to ensure resilience we must live well within our carrying capacity and not cause irreversible shifts in ecosystem states.

❖ **Limiting Nutrient**

The abundance and diversity of organisms in an ecosystem is often controlled by the weakest link or limiting factor within an ecosystem which keeps the system in check. Justus Liebeg first proposed the concept of a limiting nutrient when he observed that the growth of crops was often limited by whatever essential element was in short supply, regardless of whether the amount required was large or small. Liebig's Law of the Minimum has come to mean that growth is limited by that nutrient that is least available. For example life in freshwater streams is often limited by the amount of phosphorus in the system. Phosphorus, a key building block of genetic material and the energy molecule ATP found in cells, is released slowly in nature through the breakdown of mineralogical processes. It is estimated that global phosphorus release has been amplified 400% by post-industrial human activities, greatly influencing ecosystem food webs and services, often destroying the complex biological communities that had evolved in a low phosphorus environment.[93]

❖ **Steady State**

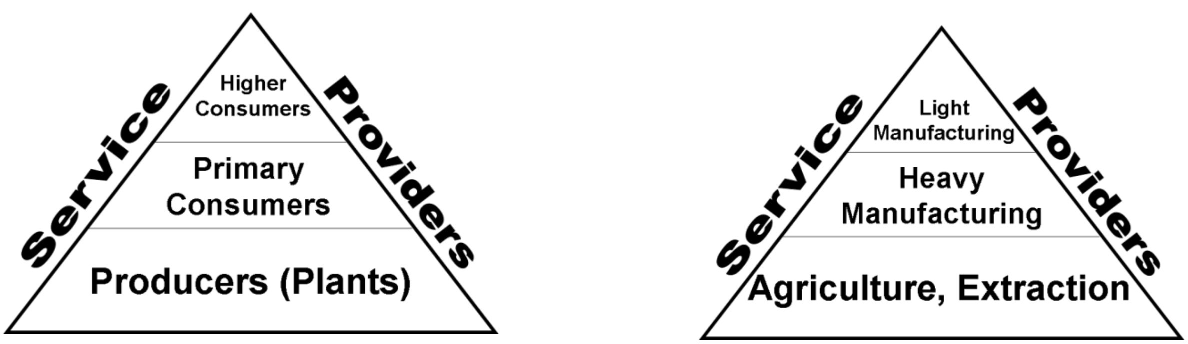
A steady-state economy, as envisioned by Herman Daly, has a constant stock of people and artifacts maintained at some desired, sufficient level by low rates of maintenance throughput, which specifically means the lowest feasible flows of matter and energy from the first stage of production to the last stage of consumption.[94] A steady-state is now required because, according to Daly, we are reaching a 'full-world' in which the opportunity cost of economic growth is significant in terms of decline in ecological services. As growth moves from the empty world to the full world, the welfare from economic services increases while the welfare from ecological services diminishes. For example, as we cut trees to make tables, we add the economic service of the table (holding our plates) and lose the ecological service of the tree in the forest (photosynthesis, preventing soil erosion, wildlife habitat, etc.).

A key component in determining where the economic limit lies is at the intersection of the marginal utility of increased production (declining trend line as we satisfy most pressing needs first) and the marginal disutility of increased consumption (rising trend line because easiest environmental sacrifices are made first). Eventually an economy can reach a "futility limit" where no further well-being is derived from increases in production.[95] Some argue we are already past this point. (See Appendix J for graphics illustrating these models.) This concept is particularly important in addressing the questions of scale and sustainability. The appropriate scale of an economy or an industry relative to its environment must be determined if society is to operate sustainably. A criticism of the steady state concept lies in the lack of hard quantifiable units in measuring utility. However, the increasing sophistication of subjective measurements and polling around well-being may overcome this criticism.

❖ **Trophic Structure (Energy Limit)**

All ecosystems have a trophic structure which shows the flow of energy from the sun to the producers (autotrophs or plants) and then on to primary, secondary and tertiary consumers (heterotrophs or animals). Only plants, algae and cyanobacteria, all of which have chloroplasts, are able to produce food by harnessing the energy from the sun through photosynthesis. Primary consumers consist of herbivores, such as insects or grazing animals, while secondary or tertiary consumers are meat eaters or omnivores (foxes, humans, etc.). The vast amount of the sun's energy captured by plants, over 90%, is lost as heat (metabolism or maintenance of the organism) as it moves up the trophic structure. A simplified example of this is that ten tons of grass can support one ton of rabbits and one-tenth of a ton of foxes. This explains why there are rarely ecosystems with more than three or four trophic levels. The dynamic stability hypothesis states that the longer the food chain the less stable the system since fluctuations at lower trophic levels are magnified at higher levels, potentially causing extinction of top predators.[96]

The trophic structure of the human economy reflects the same ecological principles.[97] The producers are farmers and extractive sectors such as fishing, logging and mining, which occupy the foundation of the economy. The size of the human economy depends upon the size of this foundation, which is ultimately limited by the flow of sunlight. Expansion at the top of the pyramid can only go so far before it breaks the foundation upon which it sits as illustrated in the diagrams below.



The Trophic Structure of the Human Economy. Source: Brief on the Trophic Structure of the Human Economy by www.steadystate.org

❖ **Net Primary Productivity as Exclusive Energy Source for Living Organisms**

Studies analyzing the impact of the human species on trophic structure show an alarming trend of vast over-appropriation of the products of photosynthesis (net primary productivity and the foundation of the global trophic pyramid, as described above) to humans. Peter Vitousek et al estimated that while only four percent of terrestrial net primary production (energy captured by plants) is used directly by humans and domestic animals as food and fiber, some 34 percent is taken by humanity through indirect destruction of primary productive land through activities such as clearing forests, causing desertification, and urban sprawl.[98] The Human Appropriation of Net Primary Productivity (HANPP) reduces the amount of energy available to all other species (an estimated 8.7m other species on Earth). It influences carbon flows between vegetation and the atmosphere, energy flows between food webs, and it influences biodiversity, water flows and biogeochemical cycling. Corporate appropriation of Net Primary Productivity could be directly calculated through existing methods and through remote sensing and satellite mapping tools. (See also the description of the Ecological Footprint method in Appendix G.)

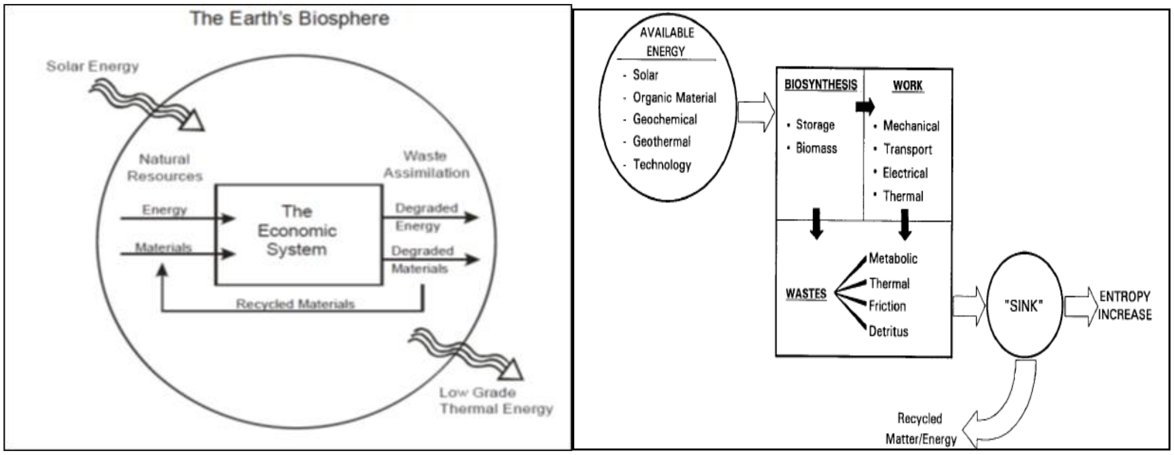
❖ **Energy Subsidy**

As illustrated in the above description of the Human Appropriation of Net Primary Productivity, the human species takes far more energy from ecosystems than required for direct food consumption. We use this energy for far more activities than to maintain our bodies, from driving cars to communications. Energy subsidies are actually common in nature. Tide pools or salt-marshes are productive systems that depend on energy subsidies through periodic flooding or influxes of nutrients. Subsidies are not inherently problematic, but can be a problem for the ecosystem when they end. Human reliance on fossil fuels is a massive ecological subsidy, taking photosynthetic product from the past and using it within a relatively short period of time.

❖ **The Second Law of Thermodynamics**

According to the Second Law of Thermodynamics, energy and matter have a tendency to disperse (The first law states that energy in the universe is constant). The importance of thermodynamics in explaining ecosystems and life on Earth was outlined in a paper by Eric Schneider and James Kay titled "Life as a Manifestation of the Second Law of Thermodynamics."[99] Thermodynamic concepts are also becoming increasingly utilized in understanding resource depletion, energy flows and economics. Thermodynamic concepts such as entropy—the measurement of the randomness or dispersal of materials; the higher the entropy the lower the ability (more dispersed) to do work; energy, exergy (maximum work potential), emergy (embodied solar energy)—are being used more frequently in guiding the understanding of environmental sustainability.[100,101] The entropy law is regarded as the main 'taproot' of these concepts and of economic scarcity.[102]

Nicholas Georgescu-Rogen understood the "Entropy Law" as a determinant of economic scarcity and therefore a useful concept in understanding sustainability. If an economic process is entropic, he argued, then economic growth should be curbed or even reversed.[103] This view was further explored by Herman Daly and Jeremy Rifkin.[104,105] The dissipative nature of the entropic process does not fit into conventional economic models, which do not account for irreversibility.[106] The economic process is sustained by the one-directional flow of energy and materials that enters as low entropy (high exergy) inputs which are then degraded irreversibly to high entropy (low exergy) outputs in the form of low-grade waste heat and waste materials. The economy can be thought of as a dissipative structure dependent on its environment, as shown below.[107]



The 2nd Law of Thermodynamics and the Economy. Two models illustrating how the economic and industrial processes take energy and material and increase entropy. Sources: Corning and Kline, Thermodynamics, Information and Life Revisited, Part II: Thermoeconomics and Control Information, Systems Research and Behavioral Science, 15, 453-482 1998. Hammond and Winnett, The Influence of Thermodynamic Ideas on Ecological Economics: An Interdisciplinary Critique, Sustainability 2009, 1, 1195-1225

Past agrarian societies depended on abundant energy as low entropy (high exergy) via solar radiation for growth of their food and the storage of excess energy in their livestock. In contrast, industrial economies depend on terrestrial resources accumulated over geological timescales such as fossil fuels and minerals. Approaches such as Total Cost Assessment and Life Cycle Assessment (LCA) are now being improved upon through contributions in the field of thermoeconomics, which not only allows for analysis of energy use from renewable and nonrenewable resources, but also accounts for the embedded solar input and the degradation of materials.

❖ Resource Partitioning

An ecological niche is the total species' use of biotic and abiotic resources in its environment. There are two possible outcomes of competition between species having identical niches: either the less competitive species will be driven to local extinction, or one of the species may evolve through natural selection to use a different set of resources. This differentiation of niches that enables similar species to coexist in a community is called resource partitioning. Humans, some argue, need to evolve better resource partitioning practices to leave more resources for the millions of other species on the planet.

❖ Maximum Sustainable Yield (MSY) and Sustainable Assimilative Capacity

According to Daly, for the management of renewable resources there are two obvious principles of sustainable development: 1) that harvest rates should equal regeneration rates (sustained yield); 2) that waste emission rates should equal the natural assimilative capacities of the ecosystems into which the wastes are emitted. Regenerative and assimilative capacities must be treated as natural capital, failure to maintain these capacities must be treated as capital consumption, and therefore not sustainable. For nonrenewable resources, it is possible for exploitation in a quasi-sustainable manner by limiting their rate of depletion to the rate of creation of renewable substitutes.[108]

The calculation of maximum sustainable yield was first proposed by Leibniz between 1646 and 1716; in 1844 Verhulst added the logistic curve to explain population growth. In the 1930s the concept gained more traction among biologists who wanted to track how many animals or fish could be extracted from an ecosystem without causing the population to collapse. MSY ultimately became the holy-grail of the fishing industry. In the 1950's, biologist Milner Schaefer modified the approach to MSY to use two sets of data; yield and fishing effort:

$$\mathbf{Y=Uf-bf^2}$$

Where:

Y = fishery yield for a particular effort
F = fishing fleet in terms of trawler fleet tonnage
b =constant comprising of efficiency and intrinsic growth rate of fish biomass
U =maximum fish catch/unit fishing effort

The major problem with the MSY is that it does not take into account the effects of competition, symbiotic or commensal relationships with other species, or changes in carrying capacity due to pollution or other human disturbances to the ocean. The model oversimplifies complex ecological food chains. MSY failed to prevent the collapse of the Peruvian anchovy fishery in the 1970s, and since then the indicator is used only in conjunction with other metrics to get a more holistic view of the fish population.[109]

❖ Total Factor Productivity

Total Factor Productivity (TFP) represents intangible production inputs into an economy, such as gains in efficiency, and technological innovation that allow additional utility to be extracted from primary inputs. Many argue that TFP, or the ability to leverage existing resources, is one reason why humans are not limited to the same degree as other species by the carrying capacity of ecosystems. The equation below (Cobb–Douglas form) represents total output (Y) as a function of total-factor productivity (A), capital input (K), labor input (L), and the two inputs' respective shares of output (α and β are the capital input share of contribution for K and L respectively). An increase in either A, K or L will lead to an increase in output. While capital and labor input are tangible, total-factor productivity is intangible, as it can range from technology to increases in knowledge and human capital.

$$Y = A \times K^{\alpha} \times L^{\beta}$$

Where:

Y = widgets/year
L = man-hours/year
K = capital-hours/year
α, β = pure numbers due to being exponents
A = (widgets * yearα + β – 1)/(caphrα * manhrβ), a balancing quantity, which is TFP

Changes in TFP can be regarded as one measure of sustainability, viewed as the change in the productive capacity of the system. An increase or stability in the TFP equates to sustainability, while a decrease indicates unsustainability. Among criticisms of this concept are that it is primarily an economic approach, and although it can give general guidance on red flags of unsustainability, especially if one is pouring too many inputs into a system and getting declining outputs, the model does not indicate if this may be due to short term effects.

- **Gaia Principle**

The Gaia principle proposes that all organisms and their inorganic surroundings on Earth are closely integrated, forming a single and self-regulating, complex system that maintains the conditions for life on the planet. The investigation of the Gaia hypothesis focuses on observing how the biosphere and the evolution of life forms contribute to the stability of global temperature, ocean salinity, oxygen in the atmosphere and other factors of habitability in a preferred homeostasis. The Gaia hypothesis was formulated by the chemist James Lovelock and co-developed by the microbiologist Lynn Margulis in the 1970s. Initially received with hostility by the scientific community, it is now studied in the disciplines of geophysiology and Earth-system science, and some of its principles have been adopted in fields such as biogeochemistry and systems ecology. This ecological hypothesis has also inspired analogies and various interpretations in social sciences, politics, and religion.[110]

- **Product-Service System (PSS) Principle**

New business models need to arise that transcend the traditional premise of selling more material products. One way to do this is to extend producer responsibility along the entire product life cycle which would reposition consumers as users where products are hired/leased/rented for as long as the product is needed. No purchase necessary. This is referred to as the product-service system (PSS). Examples are car sharing, chemical management, and washing services to name a few. This approach decouples business profits and consumer spending from material flows. It also eliminates damaging traditional business practices such as planned product obsolescence or producing poor quality products that enter landfills soon after production.[111]

- ### Life Cycle Management

Life Cycle Management studies and manages the production process in its entirety, from raw materials sourcing to production and to eventual disposal. It requires large amounts of data on inputs, outputs and various types of environmental emissions during the production process. Nationwide standardized input-output coefficients are in place. The challenge is where to set system boundaries. Product life cycle management takes many forms. The cradle-to-cradle model, for example, is a closed loop systems in which every ingredient is designed to be safe and beneficial—that is, to either naturally biodegrade or provide high quality resources for subsequent generations of products. This system allows manufacturers to generate and recover value, rather than losing material assets when a product moves out the warehouse door. William McDonough, a pioneer in this area, has been working with the US Environmental Protection Agency to develop benchmarks that can be presented to industry as alternatives to regulation.[112] Zero-to-landfill is similar, self-explanatory model.

- ### Benefit-Cost Analysis

Benefit-Cost Analysis measures the net benefits of alternative decisions by assessing the change in welfare for each individual in the society affected by the policy choice. Net benefits are assigned a monetary value, with a discount applied to future net benefits, under a set of alternatives. Most benefit-cost analysis approaches then aggregate the individual net benefits. Alternative approaches involve integrating life-cycle analysis and methods of valuing ecosystem services. One criticism is that discounting can be a weak approach to valuing future long-term benefits such as preservation of natural systems or protecting against long-latency diseases. The reliance on monetary units can also be a drawback.

- ### Ecosystem Services Valuation

Goods and services that contribute to human well-being are usually valued using a monetary metric. This approach involves having an understanding of ecological, economic and social sciences to understand how natural system contributes to “well-being” valuation. It is difficult to overstate how often this system is utilized, how powerful it is considered, or how rapidly variations on it have been evolving and developing.[113]

- ### Adaptive Management and Ecological Resilience

Gunderson and Holling described ecosystems as a “panarchy,” a nested set of self-organizing systems, each exhibiting cyclical behavior.[114] They believe that this model can be applied to human social systems as well as to natural systems. Each subsystem in a panarchy goes through “adaptive cycles,” starting with exploitation, followed by conservation. Holling added two additional stages: release (or creative destruction, as some have called this stage) and reorganization. The latter two stages correspond approximately to the process of restructuring that takes place in the movement of a complex system to a new, different attractor (or equilibrium) or to what was the original state. Indicators of environmental stress and early-warning signals are vital in high resource-use industries, especially as environmental damage and changes to ecological resilience often occur abruptly. Examples of indicator systems are buffering capacity and thresholds limits.

Holling has argued that adaptive cycles are a fundamental property of living systems and that such systems can adapt to stresses in such a manner that each succession maintains properties deemed to be healthy. He has defined sustainability as “the ability to create, test, and maintain adaptive capacity” and development as “the process of creating, testing, and maintaining opportunity.” In his argument, he uses normative terms, such as resilience, wealth and opportunity to characterize a particular form of succession, where each cycle retains many of the normatively positive properties of the preceding one and perhaps even adds more desirable traits. Putting all this together, Holling suggests that properly managed adaptive cycles constitute sustainable development. Both Holling and Kay go on to speak of adaptive management, that is, carefully monitoring the outcome of the implementation of any manmade design and adjusting social and technological structures to avoid a move into another attractor. This does not mean reducing observations to “scientific” laws and principles. Rather, it means learning and applying broad rules derived from experience.

Ecosystem Principle II: Abundance and Diversity

The diversity of an ecosystem speaks to the variety of species and ecological processes that occur in different physical settings. Below are some examples of concepts addressing the principle of diversity.

❖ Island Biogeography

MacArthur and Wilson proposed the theory of island biogeography in 1967 to explain the number of species on islands. Island refers to any suitable habitat surrounded by an expanse of unsuitable habitat.[115] The concept was revolutionary in explaining the number of species found in any location. The number of species present, they proposed, was found at the intersection of species immigration and emigration (or extinction) curves. The slope of the immigration curve is determined by the distance of an island from the mainland, while the slope of the emigration curve is determined by the size of the island and habitat heterogeneity. Larger islands with larger and more diverse habitats can support a far greater number of species, and that is why so many naturalists lament the loss of large tracts of natural habitat, as they are key in not only preserving a large number of species, but also in supporting top predators that require a large foundational trophic structure. Large populations are also necessary in providing a healthy gene pool, the key component driving the evolutionary process. The model has been used to help determine the necessary size of national parks (a type of island in a sea of development). Daniel Simberloff went on to test and validate this model using mangrove islands and the immigration and emigration rates of insects post fumigation of entire islands in the Florida Keys.

❖ Indicator Species

Biologists and ecologists often use the concept of indicator species to measure the health of an entire ecosystem. These are usually a limited number of species that are particularly sensitive to environmental disturbances and pollution. If these species are missing from a system, then it can be assumed that the ecosystem is not in good health. A classic example is the EPT (Ephemeroptera, Plecoptera and Trichoptera) indicator used in measuring water quality in rivers. The presence of these aquatic insect species indicates that the stream has a relatively undisturbed river bottom with high levels of dissolved oxygen and likely a healthy aquatic plant community, and diverse aquatic insect food-web, as all are prerequisites for these species to flourish. This approach is extremely efficient because collecting these indictors species is often much faster and more cost effective than processing water quality samples and conducting a detailed physical study of the river. Using indicator species, however, does not provide a detailed overview of the ecosystem.

❖ Biodiversity

Biodiversity indicates not only the number of species in an ecosystem, but their relative abundance as well. A commonly used indicator is the Shannon-Wiener Index which measures the number of species and the number of individual of each species (abundance). If lake A and lake B both have ten fish species, and lake A has 1,000 individuals from a carp species and only ten individuals from the remaining nine species, it has far less biodiversity then lake B, which has 100 individuals from each of the ten species. The power of the indicator is that it is very intuitive and expresses biodiversity as a single number. However, it can be very hard to determine the total number of individuals in a large ecosystem and the indicator doesn't have a qualitative element that captures the differences in the species that compromise that diversity. For example an ecosystem may have a large diversity of low-quality invasive species.

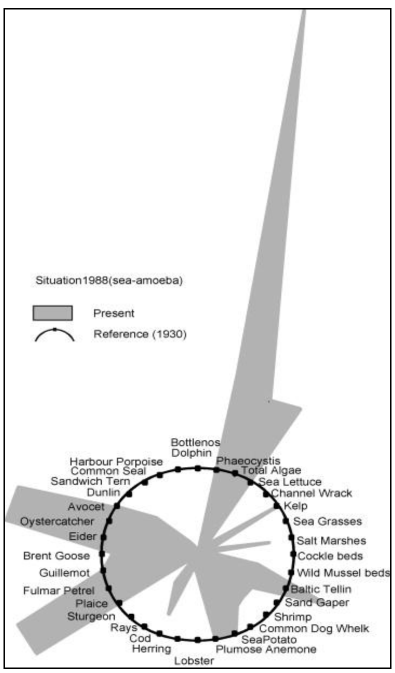
❖ Continuum

Continuums are a way of understanding the nature of, and linkages existing in, open natural systems. A classic example is the River Continuum Concept (RCC), developed by Robin Vannote in 1980, a model for classifying and describing the physical and biological characteristics of a river from the network of tiny headwater streams down through the landscape until a large river empties into the sea.[116] It is one of the foundational concepts in the study of limnology. Using the RCC, an ecologist can name one of the classifications of an upland stream and the name instantly will impart the structure of the biotic community in the river at that point and the likely physical and topographical characteristics, such as the amount of light in the water and relative depth of the river. The model also allows for a view of the river as a holistic system and makes clear connections between the organisms in different parts of the river as the river grows and moves seaward. A critique of the model is that it does not account for disturbances to rivers such as those from dams and that the concept must keep in context the region that a river is being studied. See Appendix K for an illustration.

The concept of continuum, a spectrum of thinking that can be undertaken in any problem-solving exercise, is also now being applied to research around sustainability. Sustainability, according to Bell, ranges from reductionist on one side and holistic on the other (see Appendix L). The political and rhetorical views of sustainability tend to be on the holistic side of the spectrum, and the sustainability indicators and those who measure and use them tend to be on the reductionist side.[117]

❖ AMOEBA Approach

AMOEBA is a Dutch acronym which stands for 'general method for ecosystem description and assessment'. It was developed by ecologist Ten Brink in 1991 to reflect the abundance of an ecosystem relative to a reference system. Its major strength is its highly visual approach to encapsulating sustainability and targeting the non-specialist in mind. Brink viewed three categories of 'valuable characteristics, whose sustainability is desirable': 1) yield, 2) biodiversity and 3) self-regulation. Self-regulation relates to the resilience or stability of the system as well as the abundance. The AMOEBA approach picks a reference ecosystem, either one that is relatively pristine and comparable to the ecosystem being studied, or the same ecosystem before it was disturbed by human influence. Below is an example using the approach in the Wadden Sea, comparing 1988 data on species abundance with 1930 data as a reference. The areas in gray represent the data from 1988 and the black ring show the data from 1930. The AMOEBA shows a greater number of Phaeocystis and Algae, and a relatively healthy number of Avocet, Oystercatcher, Eider, Fulmar Petrel and Plaice Sturgeon species and relatively few other species versus 1930. Critics of this approach say that, although it does provide a good snapshot of the number and abundance of species within an ecosystem, it is not a ‘pressure’ indicator—that is, an indicator that captures the forces influencing an ecosystem. Another weakness is the need to pick a reference condition, a decision that can be fraught with problems ranging from picking an inappropriate one to trying to find one at all.



Amoeba Approach to capturing ecosystem biodiversity. Source: Turnhout, E. et al. Science in Wadden Sea policy: from accommodation to advocacy, Environmental Science and Policy, May 2008

Ecosystem Principle III: Manage Uncertainty

Managing uncertainty is, to some, a metaphor of adaptive capability. Society's drive to make concepts simple and reproducible can obscure the true nature of a system, including its complexity. The complexity of sustainability mimics the complexity of natural ecosystems. Below are some examples of concepts across a variety of disciplines addressing the principle of managing uncertainty.

❖ **Managing Complexity**

Ecologists stress the need to study and understand the interconnectedness of communities and their complexities using natural ecosystems as a metaphor. Industrial Ecologist John Ehrenfeld postulates that human societies should adapt much in the same way that natural systems adapt. Nature never does anything intentionally. It just changes as conditions change. And it often changes, in unpredictable ways, moving, if sufficiently perturbed, from one attractor to another. Attractor is a technical term describing a quasi-stable, interrelated set of behavioral patterns. Complex systems demand a fundamentally different ways of thinking beyond 'cause-and-effect.'[118]

❖ **Self-Organizing Holarchic Open systems (SOHO) concept**

James Kay proposed the self-organizing holarchic open systems concept to address the dynamics of ecosystems and human systems. Holarchic simplistically refers to the concept of a system where the whole is governed by its parts.[119] Ecosystems are self-organizing meaning that their dynamics are a function of positive and negative feedback loops. This precludes linear causal explanations of ecosystem dynamics. They are driven by high quality energy pumped into them (such as the sun), and then moved far from equilibrium by the fluxes of material and energy across their boundaries and through their continuous dissipation of energy. This is done at the cost of increasing the entropy (randomness) of the larger global system in which the dissipative structure is embedded. Non-living organized systems (like lasers and tornadoes) and living systems (from cells to ecosystems) are dependent on outside energy fluxes to maintain their organization.

After drifting far enough from thermodynamic equilibrium, ecosystems may move from one steady-state to an entirely new one, similar to the rapid turnover of water layers in shallow lakes during Spring and Fall. Therefore many complex ecosystems have multiple possible operating states and may shift or diverge spontaneously from any one of them. An example is an inundated forest marsh ecosystem typically found in Canada with a community of silver and maple trees that tolerate flooded conditions for about 40% of the growing season. The feedback mechanism that maintains the swamp state is evapotranspiration (water pumping) by the trees. Too much water overwhelms the pumping capability of the trees and the system collapses, giving way to a completely different community of herbaceous marsh vegetation.

James Kay stresses the necessity of understanding the spatial and temporal scales and environmental factors that cause these 'flips' from one attractor to another, disabling one feedback system while enabling another, if we are to understand sustainability.[120]

❖ Post-Normal Science and Complex Systems Thinking

Values can no longer be left in the background when it comes to design of social and technological structures within complex systems. Silvio Funtowicz and Jerome Ravetz proposed in 1993 the concept of Post-Normal Science as a method of inquiry that is appropriate for cases where 'facts are uncertain, values in dispute, stakes high and decisions urgent'.[121,122] It is primarily applied in the context of long-term issues where there is less available information than is desired by stakeholders. Ecologists and advocates for this approach say it is relevant when the decisions are of great importance, but where not all the factors are necessarily knowable, making it directly relevant for sustainability. James Kay, an ecologist who focuses on complexity and thermodynamics, took the idea one step further by recognizing the potential for gaps in knowledge and understanding and that one should not necessarily attempt to resolve or dismiss contradictory perspectives of the world (whether they are based on science or not), but instead incorporate multiple viewpoints into the same problem-solving process.[123] Because of the complexities of sustainability, a more holistic decision making process such as provided by post-normal science could point a way forward. An illustration of this concept was around the question of whether light is a particle or a wave. For a long time there was a debate on this point, where advocates on both sides of the debate had many valid arguments based on scientific perspectives, but were lacking the theory that would resolve the conflict. And then there was a revolution in thinking that made it possible for both theories to be true.[124]

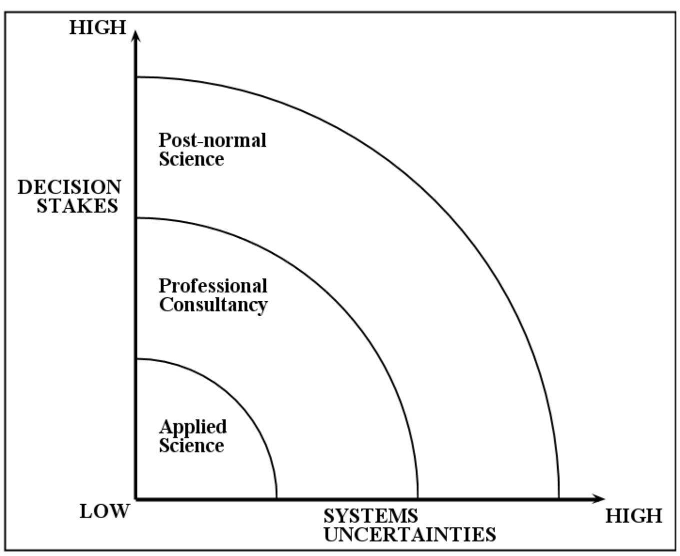


Figure 2: Using Post-Normal Science in decision making. Increasing decision stakes and systems uncertainties entail new problem solving strategies. Source: Wikipedia based on diagram by Funtowicz, S. and Ravetz, J., Science for the post-normal age, Futures 1993

❖ Cybernetics

Given how complex the concept of sustainability is, some say it would benefit from tools offered by systems approaches such as cybernetics. Cybernetics is the science of communication and control theory.[125] Cybernetics involves understanding feedback loops and control systems in order to explain how the world works from a scientific perspective. It also involves understanding that individuals construct their own "reality," which necessitates tolerance of alternative views. It also involves reflection on the understanding of multiple realities and the means by which these can be contained in a consensus view.[126]

❖ Artificial Neural Network

In order to deal with uncertainty and the complexities around a concept such as sustainability an Artificial Neural Network (ANN) model could be established to help drive decisions. ANN mimics a neuron that collects signals along dendrites and "fires" a signal to the terminal buttons once the aggregate input from these connections exceed a certain threshold. ANN is good for aggregating data with specific firing rules. Inputs can be weighted differently and thresholds can be varied. Overall, it is a flexible and sophisticated approach for identifying patterns in data and choosing indicators on a more unbiased, scientific basis, although there is still potential for some bias in terms of initial selection of the indicators to be fed into the model. Rowland proposed using ANN to compose a list of Sustainability Indicators in his study of ecosystem integrity around a Canadian Military base in Manitoba.[127] Instead of creating a set of indicators for a sustainable ecosystem and the justifying their use (a process often reflecting the researchers' biases), Rowland proposed employing an ANN to select the indicators. (See Appendix M for diagram examples.) ANN could be used in tracking pollution from individual corporations within a certain industry. Once all of the corporations' pollution reaches a certain aggregated threshold level it could trigger new pricing or regulatory levels.

❖ Ontology

Using the concept of ontology to organize knowledge from across different issues and disciplines could help advance our understanding of sustainability. Ontology deals with how entities can be grouped in a hierarchy and subdivided according to similarities and differences. One problem with studying sustainability is that each discipline looks at it differently amid an ocean of relevant issues and data. Ontology creates a layered model, where the first layer stores raw data, the second stores structured concepts, and the third traces multi-perspective conceptual chains exploring divergent approaches. The last layer assembles the existing knowledge for a solution to the original problem. An ontological development tool named Hozo at www.hozo.jp is often used to aid in problem solving across a variety of disciplines.[128]

- **Environmental Justice Tools**

Environmental justice refers to the need to redress the inequitable distribution of environmental burdens in society. A great deal of research and discussion has taken place around the concept of environmental justice especially by agencies such as the EPA. Examples of environmental justice measurement tools are 1) cumulative risk assessment to fully account for combined effects of multiple exposures (physical, chemical, biologic, psychosocial) on a community, and 2) cumulative impact analyses to set priority areas and direct resources to most impacted communities.

- **Precautionary Principle**

The precautionary principle states that if an action or policy has a suspected risk of causing harm to the public or to the environment, in the absence of scientific consensus that the action or policy is harmful, the burden of proof falls on those taking the action. A nation that fully incorporates this approach in its decision-making processes would likely be well on the way towards a sustainability.

- **Risk Assessment and Risk Management**

The National Research Council produced a report in 1983 entitled 'Risk Assessment in the Federal Government: Managing the Process' with the goal of helping federal agencies make informed decisions around chemical agents, public concern and links between toxins and adverse effects such as cancer and birth defects. A four-step risk assessment paradigm, adopted and still used by the EPA, includes: hazard identification, dose-response assessment, exposure assessment and risk characterization. See Appendix N for illustration of the model. Since 1983 risk assessment and analytical tools and technology have evolved and been revised. New techniques involve assessing dose responses on children versus adults and the impact of multiple stressors and doses calling for more cumulative risk assessments. The OECD Chemicals Program also plays a central role in evolving chemical risk assessment through work on the 'Mutual Acceptance of Data' and the "Code of Good Laboratory Practices." (A recent registration requirement showed over 100,000 chemical substances are in use in the European Union, a number far greater than expected.)[129] Ultimately the EPA views sustainability as going beyond risk management, as it is a concept seeking to maximize benefits.

- **Proper Coupling**

Proper coupling occurs when the behavior of one system affects the behavior of one or more other systems in a desirable manner, using the appropriate feedback loops, so that systems can work together in harmony in accordance with design objectives. For example, if you never got hungry, you would starve to death. You would be improperly coupled to the world around you. Sustainability can be seen as the human system being properly coupled to the greater system within which it functions: the environment.[130]

- **Sustainability Impact Assessments**

There are many types of impact assessments: environmental, poverty, regulatory, integrated and several others. Sustainability assessment is gaining in popularity especially in Europe and Canada and integrates analyses of economic, social and environmental variables from proposed policy changes. It seeks to optimize policy-decision's contribution to sustainability versus traditional approaches seeking to minimize environmental impacts.[131] Several nations and agencies actively use this approach.[132] Key components are broad stakeholder involvement, impact analysis using select tools and methods, identification of conflicts and trade-offs across economic, social and environmental pillars, proposal of mitigating measures and alternative options.[133] One criticism of this approach is that practitioners focus too much on sustainability-oriented processes versus delivering sustainable outcomes.[134] To avoid this, long-term studies to test the effectiveness of projects or policy goals are put in place. Also, there are proposals to formalize the requirement of accounting for any trade-offs and explicit justifications in the decision-making process.[135]

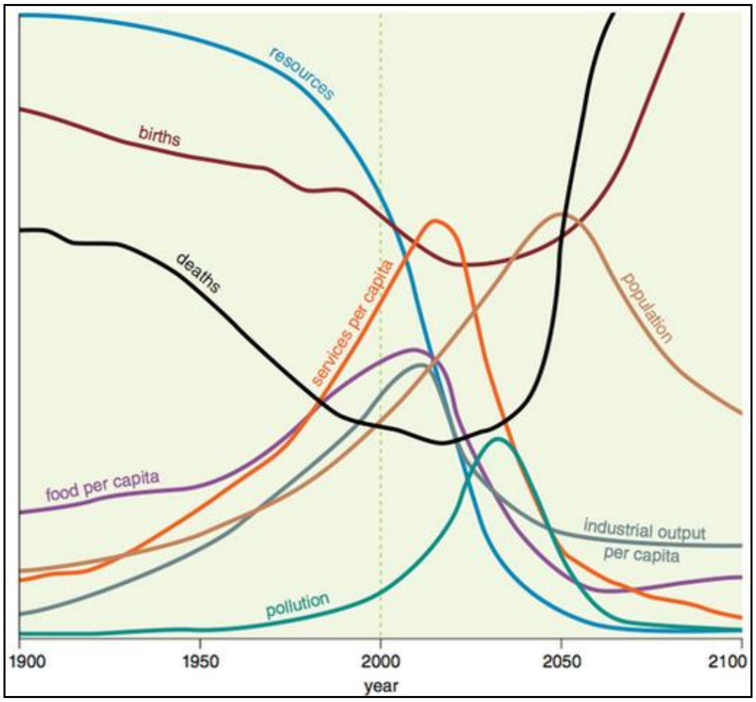
Conclusion

An opportunity exists to capitalize on the growing momentum in the public dialogue and policy-circles on moving toward a more sustainable society. The principles discussed above and the advances made in a wide variety of fields from law and politics to life sciences and engineering offer new approaches and potentially seeds new ideas around measuring, reporting, and analyzing corporate sustainability performance.

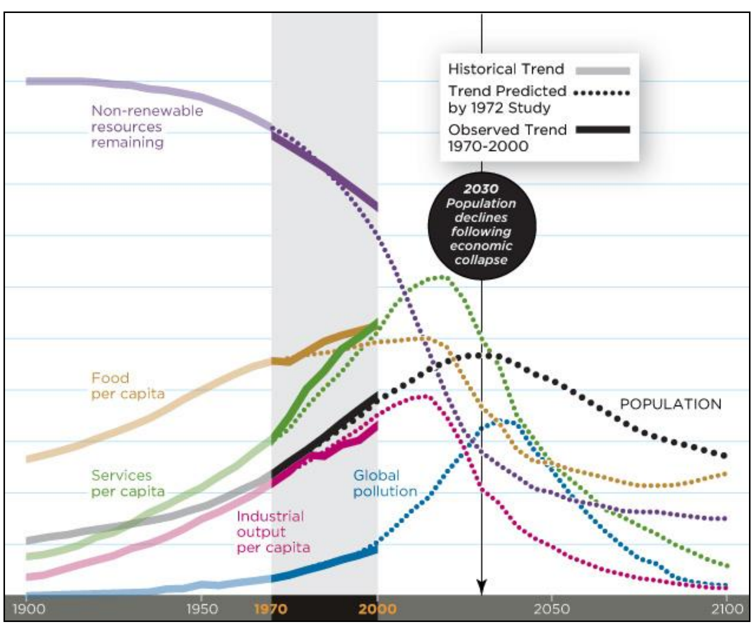
Appendices

APPENDIX A

World Model Standard Run 1900-2100 from Limits to Growth, 1972. Authors do not claim that their predictions are accurate, but say they are indicative only. Food per capita peaks in 2008, Industrial output per capita peaks in 2010, pollution in 2031, population in 2050 Source: Limits to Growth A report for the Club of Rome's project on the predicament of mankind by D.H. Meadows, D.L. Meadows, J. Randers and W.W. Behrens III (1972) page 124



Looking Back on the Limits of Growth by Mark Strauss of the Smithsonian Magazine April 2012



APPENDIX B

The United Nations Conference on Environment and Development, 1992, Principles:

Principle 1: Human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature.

Principle 2: States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental and developmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction.

Principle 3: The right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations.

Principle 4: In order to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it.

Principle 5: All States and all people shall cooperate in the essential task of eradicating poverty as an indispensable requirement for sustainable development, in order to decrease the disparities in standards of living and better meet the needs of the majority of the people of the world.

Principle 6: The special situation and needs of developing countries, particularly the least developed and those most environmentally vulnerable, shall be given special priority. International actions in the field of environment and
development should also address the interests and needs of all countries.

Principle 7: States shall cooperate in a spirit of global partnership to conserve, protect and restore the health and integrity of the Earth's ecosystem. In viewof the different contributions to global environmental degradation, States have common but differentiated responsibilities. The developed countries acknowledge the responsibility that they bear in the international pursuit of sustainable development in view of the pressures their societies place on the
global environment and of the technologies and financial resources they command.

Principle 8: To achieve sustainable development and a higher quality of life for all people, States should reduce and eliminate unsustainable patterns of production and consumption and promote appropriate demographic policies.

Principle 9: States should cooperate to strengthen endogenous capacity-building for sustainable development by improving scientific understanding through exchanges of scientific and technological knowledge, and by enhancing the development, adaptation, diffusion and transfer of technologies, including new and innovative technologies.

Principle 10: Environmental issues are best handled with the participation of all concerned citizens, at the relevant level. At the national level, each individual shall have appropriate access to information concerning the environment that is held by public authorities, including information on hazardous materials and activities in their communities, and the opportunity to participate in decision-making processes. States shall facilitate and encourage public awareness and participation by making information widely available. Effective access to judicial and administrative proceedings,
including redress and remedy, shall be provided.

Principle 11: States shall enact effective environmental legislation. Environmental standards, management objectives and priorities should reflect the environmental and developmental context to which they apply. Standards applied by some countries may be inappropriate and of unwarranted economic and social cost to other countries, in particular developing countries.

Principle 12: States should cooperate to promote a supportive and open international economic system that would lead to economic growth and sustainable developmentin all countries, to better address the problems of environmental degradation. Trade policy measures for environmental purposes should not constitute a means of arbitrary or unjustifiable discrimination or a disguised restriction on international trade. Unilateral actions to deal with environmental challenges outside the jurisdiction of the importing country should be avoided. Environmental measures addressing transboundary or global environmental problems should, as far as possible, be based on an international consensus.

Principle 13: States shall develop national law regarding liability and compensation for the victims of pollution and other environmental damage. States shall also cooperate in an expeditious and more determined manner to develop further international law regarding liability and compensation for adverse effects of environmental damage caused by activities within their jurisdiction or control to areas beyond their jurisdiction.

Principle 14: States should effectively cooperate to discourage or prevent the relocation and transfer to other States of any activities and substances that cause severe environmental degradation or are found to be harmful to human
health.

Principle 15: In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty
shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

Principle 16: National authorities should endeavour to promote the internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of
pollution, with due regard to the public interest and without distorting international trade and investment.

Principle 17: Environmental impact assessment, as a national instrument, shall be undertaken for proposed activities that are likely to have a significant adverse impact on the environment and are subject to a decision of a competent
national authority.

Principle 18: States shall immediately notify other States of any natural disasters or other emergencies that are likely to produce sudden harmful effects on the environment of those States. Every effort shall be made by the international
community to help States so afflicted.

Principle 19: States shall provide prior and timely notification and relevant information to potentially affected States on activities that may have a significant adverse transboundary environmental effect and shall consult with those States at an early stage and in good faith.

Principle 20: Women have a vital role in environmental management and development. Their full participation is therefore essential to achieve sustainable development.

Principle 21: The creativity, ideals and courage of the youth of the world should be mobilized to forge a global partnership in order to achieve sustainable development and ensure a better future for all.

Principle 22: Indigenous people and their communities and other local communities have a vital role in environmental management and development because of their knowledge and traditional practices. States should recognize and duly support their identity, culture and interests and enable their effective participation in the achievement of sustainable development.

Principle 23: The environment and natural resources of people under oppression, domination and occupation shall be protected.

Principle 24: Warfare is inherently destructive of sustainable development. States shall therefore respect international law providing protection for the environment in times of armed conflict and cooperate in its further development, as necessary.

Principle 25: Peace, development and environmental protection are interdependent and indivisible.

Principle 26: States shall resolve all their environmental disputes peacefully and by appropriate means in accordance with the Charter of the United Nations.

Principle 27: States and people shall cooperate in good faith and in a spirit of partnership in the fulfilment of the principles embodied in this Declaration and in the further development of international law in the field of sustainable development.

APPENDIX C

Millennium Development Goals with linked target and indictors. Source: http://mdgs.un.org/unsd/mdg/Host.aspx?Content=Indicators/OfficialList.htm

Goal	Target	Indicators
1) Eradicated extreme poverty and hunger	1A)Halve the proportion of people living on less than $1 a day	Proportion of population below $1 per day (PPP values)
		Poverty gap ratio (incidence x depth of poverty)
		Share of poorest quintile in national consumption
	1B) Achieve Decent Employment for Women, Men and Young People	GDP Growth per Employed Person
		Employment Rate
		Proportion of employed population below $1 per day (PPP values)
		Proportion of family-based workers in employed population
	1C) Halve the proportion of people who suffer from hunger	Prevalence of underweight children under five years of age
		Proportion of population below minimum level of dietary energy consumption
2) Achieve universal primary education	2A)By 2015 all children can complete a full course of primary schooling, girls and boys	Enrollment in primary education
		Completion of primary education
		Literacy of 15-24 year olds, female and male
3) Promote gender equality and empower women	3A) Eliminate gender disparity in primary and secondary education preferably by 2005 and all levels by 2015	Ratios of girls to boys in primary, secondary and tertiary education
		Share of women in wage employment in the non-agriculture sector
		Proportion of seats held by women in national parliament
4) Reduce child mortality rates	4A) Reduce by two-thirds, between 1990 and 2015, the under-five mortality rate	Under-five mortality rate
		Infant (under 1) mortality rate
		Proportion of 1-year-old children immunized against measles
5) Improve Maternal Health	5A) Reduce by three quarters, between 1990 and 2015, the maternal mortality ratio	Maternal mortality ratio
		Proportion of births attended by skilled health personnel
	5B) Achieve, by 2015, universal access to reproductive health	Contraceptive prevalence rate
		Adolescent birth rate
		Antenatal care coverage
		Unmet need for family planning
6) Combat HIV/AIDS, malaria and other diseases	6A) Have halted by 2015 and begun to reverse the spread of HIV/AIDS	HIV prevalence among population aged 15–24 years
		Condom use at last high-risk sex
		Proportion of population aged 15–24 years with comprehensive correct knowledge of HIV/AIDS
	6B) Achieve by 2010, universal access to treatment for HIV/AIDS for	Proportion of population with advanced HIV infection with access to antiretroviral drugs

Goal	Target	Indicators
	all those who need it	
	6C) Have halted by 2015 and begun to reverse the incidence of malaria and other major diseases	Prevalence and death rates associated with malaria
		Proportion of children under 5 sleeping under insecticide-treated bednets
		Proportion of children under 5 with fever who are treated with appropriate anti-malarial drugs
		Prevalence and death rates associated with tuberculosis
		Proportion of tuberculosis cases detected and cured under DOTS (Directly Observed Treatment Short Course)[
7) Ensure environmental sustainability	7A) Integrate the principles of sustainable development into country policies and program; reverse loss of environmental resource	
	7B) Reduce biodiversity loss, achieving, by 2010, a significant reduction in the rate of loss	Proportion of land area covered by forest
		CO_2 emissions, total, per capita and per \$1 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
	7C) Halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation	Proportion of population with sustainable access to an improved water source, urban and rural
		Proportion of urban population with access to improved sanitation
	7D) By 2020, to have achieved a significant improvement in the lives of at least 100 million slum-dwellers	Proportion of urban population living in slums
8) Develop a global partnership for development	8A) Develop further an open, rule-based, predictable, non-discriminatory trading and financial system	Includes a commitment to good governance, development, and poverty reduction – both nationally and internationally
	8B) Address the Special Needs of the Least Developed Countries	Includes: tariff and quota free access for LDC exports; enhanced program of debt relief for HIPC and cancellation of official bilateral debt; and more generous ODA (Overseas Development Assistance) for countries committed to poverty reduction
	8C) Address the special	Through the Program of Action for the

Goal	Target	Indicators
	needs of landlocked developing countries and small island developing States	Sustainable Development of Small Island Developing States and the outcome of the twenty-second special session of the General Assembly
	8D) Deal comprehensively with the debt problems of developing countries through national and international measures in order to make debt sustainable in the long term	Official development assistance, market access and debt sustainability indicators*
	8E) In co-operation with pharmaceutical companies, provide access to affordable, essential drugs in developing countries	Proportion of population with access to affordable essential drugs on a sustainable basis
	8F) In co-operation with the private sector, make available the benefits of new technologies, especially information and communications	Telephone lines and cellular subscribers per 100 population
		Personal computers in use per 100 population,
		Internet users per 100 Population

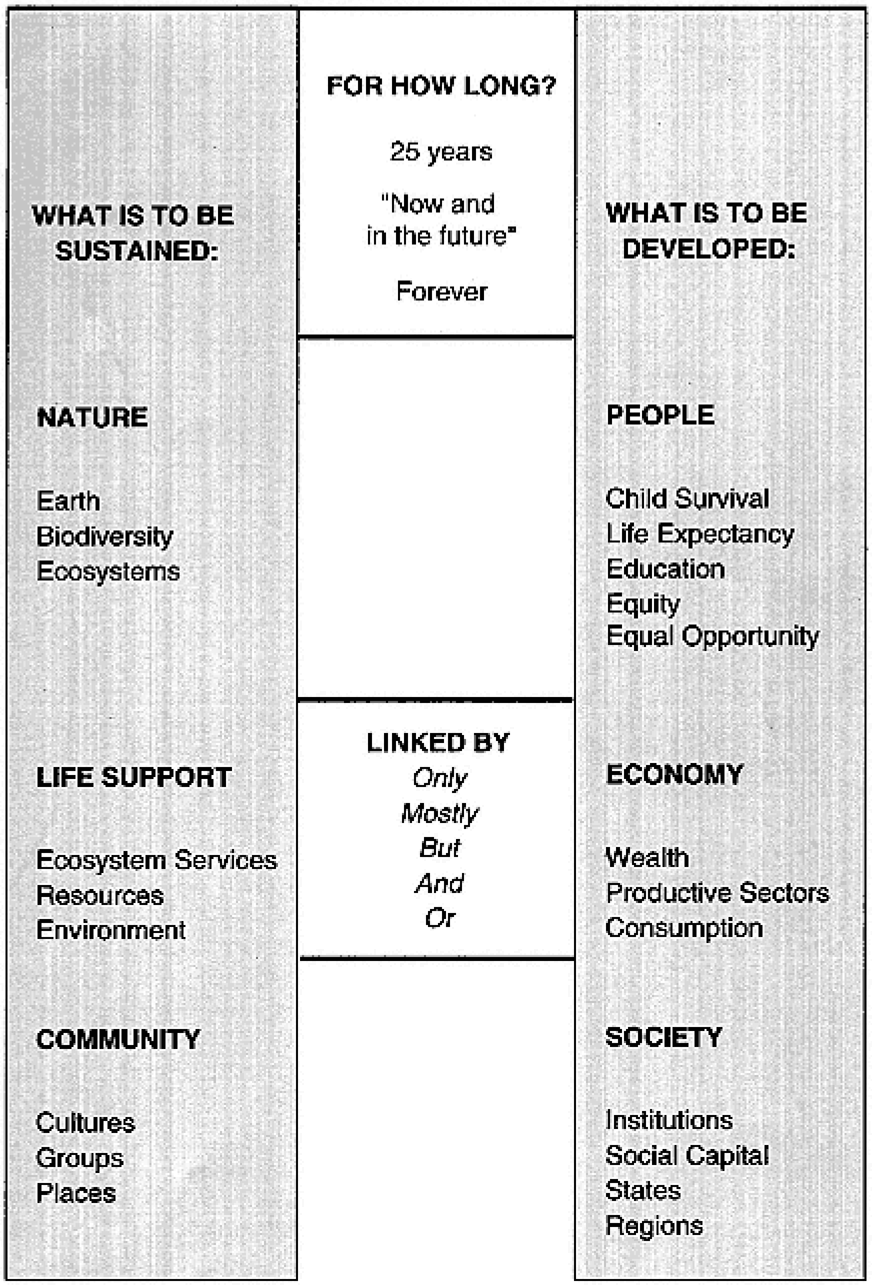
APPENDIX D

Europe 2020 a strategy for jobs and smart, sustainable and inclusive growth based on five EU headline targets. Source:Communication from Commission, Europe 2020, A Strategy for smart, sustainable and inclusive growth. Brussels 2010.

Headline Target	Indictor
75 % of the population aged 20-64 should be employed (Smart and Inclusive Growth Components)	-Employment rate (total, females, males): -The number of persons (females, males) aged 20-64 in employment as a share of the total population (females, males) of the same age group.
3% of the EU's GDP should be invested in R&D (Smart Growth Component)	-Gross domestic expenditure on R&D
Reduction of the greenhouse gas emissions by 20% compared to 1990 **Increase in the share of renewable energy sources in final energy consumption to 20%** **20% increase in energy efficiency (All Sustainable Growth Component)**	-Greenhouse gas emissions, base year 1990 -Share of renewables in gross final energy consumption -Ratio between the Gross Inland Consumption of Energy (coal, electricity, oil, natural gas and renewable energy sources – available for consumption) and the Gross Domestic Product (GDP) calculated for a calendar year and expressed in Millions of euro, chain-linked volumes, reference year 2000 (at 2000 exchange rates)
The share of early school leavers should be under 10% and at least 40% of 30-34 years old should have completed a tertiary or equivalent education. (Smart and Inclusive Growth Components)	-Early leavers from education and training by gender -Tertiary educational attainment by gender, age group 30-34
Reduction of poverty by aiming to lift at least 20 million people out of the risk of poverty or social exclusion (Inclusive Growth Component)	-Persons are defined as living in households with very low work intensity if they are aged 0-59 and the working age members in the household worked less than 20 % of their potential during the past year. -People at risk-of-poverty after social transfers. This indicator measures the share of persons at risk of monetary poverty. Persons are at risk of poverty if their equivalised disposable income is below the risk-of-poverty threshold, which is set at 60 % of the national median after social transfers. -Severely materially deprived people: ‘Material deprivation’ covers issues relating to economic strain and durables. Severely materially deprived persons have living conditions greatly constrained by a lack of resources and cannot afford at least four of the following: to pay rent or utility bills; to keep their home adequately warm; to pay unexpected expenses; to eat meat, fish or a protein equivalent every second day; a week holiday away from home; a car; a washing machine; a colour TV; or a telephone.

APPENDIX E

Sustainable development: common concerns and differing emphases from broad literature review of advocates, analysts and researchers along the topic of sustainable development. Finding are listed below outlined as what is to be ‘sustained’ and what is to be ‘developed’. Source: Board on Sustainable Development, Our Common Journey, A transition toward Sustainability, National Academy Press, 1999, page 24.



APPENDIX F

Examples of Sustainability Principles and Definitions

Brundtland Report
The ability to make development sustainable – to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs.

ACCA: Global Association for Chartered Accountants. Going Concern Publication, 2007
ACCA believes that the term '**sustainability' implies a higher level of commitment than the term 'responsibility'**. Generally speaking, an organization could claim to be a responsible organization merely by following all external regulations relating to (say) corporate law, environmental practice and employee welfare. Yet such an organization might still be contributing negatively to the environmental balance sheet as well as pursuing business strategies that might endanger both shareholder value and employee and social welfare.

John Elkington, SustainAbility, the Transparent Economy
Properly understood, sustainability is not the same as corporate social responsibility (CSR)—nor can it be reduced to achieving an acceptable balance across economic, social and environmental bottom lines. Instead, it is about the fundamental, intergenerational task of **winding down the dysfunctional economic and business models of the nineteenth and twentieth centuries,** and the evolution of new ones fit for a human population headed towards nine billion people, living on a small planet already in ecological overshoot.

Beyond the Limits (update of Limits to Growth) 1992. Meadows, D. et al, Beyond the Limits, Post Mills, Vermont, Chelsea Green Publishing, 1992, page 209
From a **systems** point of view a sustainable society is one that has in place informational mechanisms to keep in check the positive feedback loops that cause exponential population and [physical] capital growth. That means that birth rates roughly equal death rates, and [physical] investment rates roughly equal [physical] depreciation rates, unless and until technical changes and social decisions justify a considered and controlled change in the levels of population or capital. In order to be socially sustainable the combination of population, capital, and technology in the society would have to be configured so that the material living standard is adequate and secure for everyone. In order to be physically sustainable the society's **material and energy throughputs would have to meet economist Herman Daly's three conditions: 1) Its rates of use of renewable resources do not exceed their rates of regeneration. 2) Its rates of use of unrenewable resources do not exceed the rate at which sustainable renewable substitutes are developed. 3) Its rates of pollution emission do not exceed the assimilative capacity of the environment.**

Lisbon Principles of Sustainable Governance.
www.eoearth.org/article/Lisbon_principles_of_sustainable_governance
Principle 1: Responsibility. Access to environmental resources carries attendant responsibilities to use them in an **ecologically sustainable**, economically efficient, and **socially fair manner**. Individual and corporate responsibilities and **incentives** should be aligned with each other and with broad social and ecological goals.
Principle 2: Scale-matching. Ecological problems are rarely confined to a single scale. Decision-making on environmental resources should (i) be assigned to institutional levels that maximize ecological input, (ii) ensure the flow of ecological information between institutional levels, (iii) take ownership and actors into account, and (iv) internalize costs and benefits. **Appropriate scales of governance will be those that have the most relevant information, can respond quickly and efficiently, and are able to integrate across scale boundaries.**
Principle 3: Precaution. In the face of uncertainty about potentially irreversible environmental impacts, decisions concerning their use should err on the side of caution. The burden of proof should shift to those whose activities potentially damage the environment.

Principle 4: Adaptive management. Given that some level of uncertainty always exists in environmental resource management, decision-makers should continuously gather and integrate appropriate ecological, social, and economic information with the goal of adaptive improvement.
Principle 5: Full cost allocation. *All* of the internal and external costs and benefits, including social and ecological, of alternative decisions concerning the use of environmental resources should be identified and allocated. When appropriate, markets should be adjusted to reflect full costs.
Principle 6: Participation. All stakeholders should be engaged in the formulation and implementation of decisions concerning environmental resources. Full stakeholder awareness and participation contributes to credible, accepted rules that identify and assign the corresponding responsibilities appropriately.

MIT Global System for Sustainability Development (GSSD)
To become sustainable, a social system needs to be characterized by four 'process-conditions'.
(a) Ecological systems that demonstrate **balance and resilience.**
(b) Economic and other activities that do not undermine ecological systems.
(c) Governance reflecting **participation and responsiveness**.
(d) Institutional performance demonstrating **adaptation and feedback**.
If and only if, these conditions hold will a system dispose toward sustainability.

John Enhrenfeld, Author of Sustainability by Design, page 49 and 215
I define sustainability as the possibility that humans and other life will **flourish** on the Earth forever.

Sustainability lives in a world distinct from the present: one with a new vocabulary and cultural habits. As we reach toward that new world, we remain enmeshed in our modern milieu with the vocabulary and stories that have served us so well for centuries. Until the **new story replaces the old**, we will have to, in Fitzgerald's words, hold on to two opposing models of reality and beliefs about ourselves while we use our intelligence to design the new tools and institutions that sustainability requires." F. Scott Fitzgerald, The Crack-Up.

Ehrenfeld and Gladwin's (1997) list of dominant modernist cultural paradigm with an opposing set derived from the ecosystem metaphor

Modernist Paradigm	**Sustainability paradigm**
Reductionist	Reductionist Interconnected
Simplicity	Complexity
Determinacy	Indeterminacy
Atomistic	Holistic
Mechanistic	Organic
Anthropocentric	Biocentric
Individualistic	Communitarian
Quantitative	Qualitative
Disenchantment	Enchantment
Competition	Cooperation
Geo-political boundaries	Natural boundaries
Linear, predictable	Nonlinear, unpredictable
Equilibrium	Steady-state

Thwink.org
Sustainability is the ability to **continue a defined behavior indefinitely**.
For more practical detail the behavior you wish to continue indefinitely must be defined. For example:
- Environmental sustainability is the ability to **maintain rates of renewable resource harvest, pollution creation, and non-renewable resource depletion that can be continued indefinitely**.
-Economic sustainability is the ability to support a **defined level** of economic production indefinitely.
-**Social sustainability** is the ability of a social system, such as a country, to function at a defined level of social well-being indefinitely.

The Natural Step Four System Conditions. Adapted from http://www.naturalstep.org/

Extraction of substances from the Earth's crust must not systematically increase in nature. (This means that **fossil fuels, metals, and other minerals cannot be extracted at a faster rate than their re-deposit back into the Earth's crust**).

Substances produced by society must not systematically increase in nature. (This means that things like plastics, ozone-depleting chemicals, carbon dioxide, waste materials, etc must not be produced at a faster rate than they can be broken down in nature. This requires a greatly decreased production of naturally occurring substances that are systematically accumulating beyond natural levels, and a phase-out of persistent human-made substances not found in nature.)

The **physical basis for productivity and diversity of nature must not be systematically diminished.** (This means that we cannot harvest or manipulate ecosystems in such a way as to diminish their productive capacity, or threaten the natural diversity of life forms (biodiversity). This requires that we critically examine how we harvest renewable resources, and adjust our consumption and land-use practices to fall well within the regenerative capacities of ecosystems.)
We must be **fair and efficient in meeting basic human needs**. (This means that basic human needs must be met with the most resource-efficient methods possible, including a just resource distribution.)

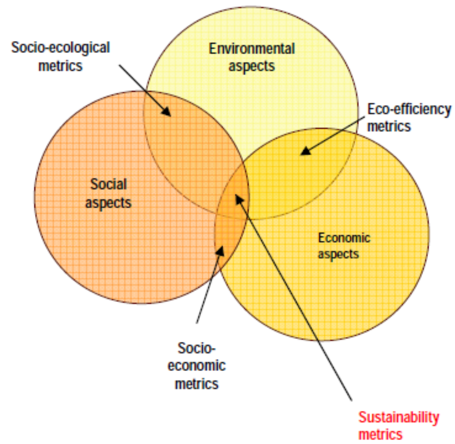
Coop America, Coop America Quarterly, No. 37 Summer 1995.
Sustainable society - Society whose long term **prospect for continuing to exist are good**. Such a society would be characterized by an emphasis on preserving the environment, developing strong **peaceful relationships** between people and nations, and an emphasis on **equitable** distribution of wealth.

ICCR, http://iccr.org/news/press_releases/dixonspeachb092304.PDF by Frank Dixon, 2003
Sustainability can only be achieved if we adopt and act from a **systems perspective**. Every person, plant, animal and thing on this planet is part of one **interconnected** system. This total system is too **complex** for any one person to understand. So we break it down into parts (reductionism) and develop solutions to problems in one area that often become problems in other areas. As the consequences of our shortsighted actions become more obvious, **firms will be compelled to take more responsibility for their negative impacts and begin acting from a systems perspective**

World Business Council on Sustainable Development, http://www.wbcsd.org/
Sustainable development involves the simultaneous pursuit of economic prosperity, environmental quality and social equity. Companies aiming for sustainability need to perform not against a single, financial bottom line but against the triple bottom line. Over time, human and social values change. Concepts that once seemed extraordinary (e.g. emancipating slaves, enfranchising women) are now taken for granted. New concepts (e.g. responsible consumerism, environmental justice, intra- and inter-generational equity) are now coming up the curve.

Office of Research and Development (ORD) of the US EPA
Our Sustainability Research Strategy rests on the recognition that sustainable environmental outcomes must be achieved in a **systems-based** and multimedia context that focuses on the environment without neglecting the roles of economic patterns and human behavior. This recognition begets a fundamental change in research design. In a systems-based approach, the traditional goals of achieving clean air or water or protecting ecosystems and human health can be
fully understood only through a multimedia approach. EPA and its partners will develop integrating decision support tools (models, methodologies, and technologies) and supporting data and analysis that will guide decision makers toward environmental sustainability and sustainable development.

Two-dimensional and three-dimensional metrics for Sustainability. True Sustainable metrics are at intersection of all three. Sikdar, S.K., Sustainable Development and Sustainability Metics., EPA 2003



Sustainable Measures, www.sustainablemeasures.com
There may be as many definitions of sustainability and sustainable development as there are groups trying to define it. All the definitions have to do with: **Living within the limits**; Understanding the interconnections among economy, society, and environment; **Equitable** distribution of resources and **opportunities**

Sustainable Community Indicator Checklist, Sustainable Measures, www.sustainablemeasures.com
-Does the indicator **address the carrying capacity of the natural resources** -- renewable and nonrenewable, local and nonlocal -- that the community relies on?
-Does the indicator **address the carrying capacity of the ecosystem services** upon which the community relies, whether local, global, or from distant sources?
-Does the indicator address the **carrying capacity of esthetic qualities** -- the beauty and life-affirming qualities of nature -- that are important to the community?
-Does the indicator address the **carrying capacity of the community's human capital** -- the skills, abilities, health and education of people in the community?
-Does the indicator address the carrying **capacity of a community's social capital** -- the connections between people in a community: the relationships of friends, families, neighborhoods, social groups, businesses, governments and their ability to cooperate, work together and interact in positive, meaningful ways?
-Does the indicator address the **carrying capacity of a community's built capital** -- the human-made materials (buildings, parks, playgrounds, infrastructure, and information) that are needed for quality of life and the community's ability to maintain and enhance those materials with existing resources?
-Does the indicator provide a long term view of the community?
-Does the indicator addresses the issue of **economic, social or biological diversity** in the community?
-Does the question address the issue of **equity or fairness** -- either between current community residents (intra-generational equity) or between current and future residents (inter-generational equity)? Is the indicator understandable to and useable by its intended audience?
-Does the indicator measure a link between economy and environment?
-Does the indicator measure a link between environment and society?
-Does the indicator measure a link between society and economy?
-Does the indicator measure or set a goal for sustainability that is **at the expense of another** community or at the expense of global sustainability?

The ten Bellagio Principles for guaging progress towards sustainable development. Source: Bell and Morse, Sustainability Indicators, Earthscan 2008 and http://www.iisd.org/pdf/bellagio.pdf for comprehensive description.
1. What is meant by sustainable development should be **clearly defined**.
2. Sustainability should be viewed in a **holistic sense**, including economic, social and ecological components.

3. Notions of **equity** should be included in any perspective of sustainable development. This includes access to resources as well as human rights and other non-market activities that contribute to human and social well-being.
4. **Time horizon** should span 'both human and ecosystem time scales' and the **spatial scale** should include 'not only local but also long-distance impacts on people and ecosystms'.
5. Progress towards sustainable development should be based on the measurement of 'a **limited number' of indicators** based on 'standardized measurement'.
6. Methods and data employed for assessment of progress should be **open and accessible** to all.
7. Progress should be effectivley communicated to all.
8. **Broad participation** is required.
9. Allowance should be made for **repeated measurement** in order to determine **trends** and to incorporate the results of experience.
10. **Institutional capacity** in order to monitor progress towards sustainable development needs to be assured.

Georgescu-Roegen's minimal bioeconomic program
First, the production of all **instruments of war, not only of war itself, should be prohibited completely**. It is utterly absurd (and also hypocritical) to continue growing tobacco if, avowedly, no one intends to smoke. The nations which are so developed as to be the main producers of armaments should be able to reach a consensus over this prohibition without any difficulty if, as they claim, they also possess the wisdom to lead mankind. Discontinuing the production of all instruments of war will not only do away at least with the mass killings by ingenious weapons but will also release some tremendous productive forces for international aid without lowering the standard of living in the corresponding countries.

Second, through the use of these productive forces as well as by additional well-planned and sincerely intended measures, the **underdeveloped nations must be aided to arrive as quickly as possible at a good (not luxurious) life**. Both ends of the spectrum must effectively participate in the efforts required by this transformation and accept the necessity of a radical change in their polarized outlooks on life.

Third, **mankind should gradually lower its population to a level that could be adequately fed only by organic agriculture**. Naturally, the nations now experiencing a very high demographic growth will have to strive hard for the most rapid possible results in that direction.

Fourth, until either the direct use of solar energy becomes a general convenience or controlled fusion is achieved, all **waste of energy – by overheating, overcooling, overspeeding, overlighting, et cetera – should be carefully avoided**, and if necessary, strictly regulated.

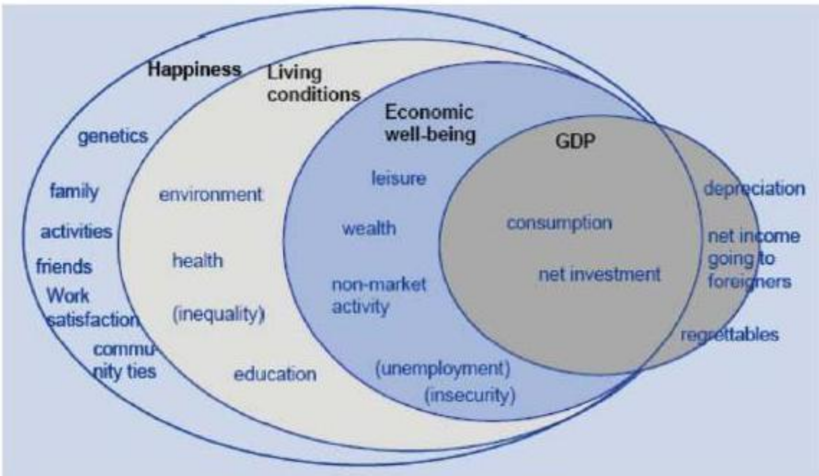
Fifth, we must **cure ourselves of the morbid craving for extravagant gadgetry**, splendidly illustrated by such a contradictory item as the golf cart, and for such mammoth splendors as two-garage cars. Once we do so, manufacturers will have to stop manufacturing such "commodities".

Sixth, **we must also get rid of fashion**, of "that disease of the human mind", as Abbot Fernando Galliani characterized it in his celebrated Della Moneta (1750). It is indeed a disease of the mind to throw away a coat or a piece of furniture while it can still perform its specific service. To get a "new" car every year and to refashion the house every other is a bioeconomic crime. Other writers have already proposed that goods be manufactured in such a way as to be more durable. But it is even more important that consumers should reeducate themselves to despise fashion. Manufacturers will then have to focus on durability.

Seventh, and closely related to the preceding point, is the necessity that **durable goods be made still more durable** by being designed so as to be repairable. (To put it in a plastic analogy, in many cases nowadays, we have to throw away a pair of shoes merely because one lace has broken.)

Eighth, in a compelling harmony with all the above thoughts we should cure ourselves of what I have been calling **"the circumdrome of the shaving machine"**, which is to shave oneself faster so as to have more time to work on a machine that shaves faster so as to have more time to work on a machine that shaves still faster, and so on ad infinitum. This change will call for a great deal of recanting on the part of all those professions which have lured man into this empty infinite regress. We must come to realize that an important prerequisite for a good life is a substantial amount of leisure spent in an intelligent manner.

The main elements of happiness and well-being from Koroneos, Christopher and Rokos, Dimitri, Sustainable and Integrated Development – A Critical Analysis, Sustainability, Vol 4, Issue 1, January 2012



Building Sustainable Future Needs More Than Science, Experts Say, By Stephen Leahy of IPS News.
Source: http://www.ipsnews.net/news.asp?idnews=106808

"We live in our heads. We live in storyland," agreed John Robinson of UBC's Institute for Resources, Environment and Sustainability. When we talk about sustainability we are talking about the future, how things could be. This is the landscape of imagination," Robinson told IPS. "If we can't imagine a better world we won't get it."

The 3rd Nobel Laureate Symposium on Sustainability (May 2011)[136]. Called for Priorities for Coherent Global Action
We recommend a dual track approach:
a) emergency solutions now, that begin to stop and reverse negativeenvironmental trends and redress inequalities in the inadequate institutional frameworks within which we operate, and
b) long term structural solutions that gradually change values, institutions and policy frameworks. We need to support our ability to innovate, adapt, and learn.

1**. Reaching a more equitable world**: Unequal distribution of the benefits of economic development are at the root of
poverty. Despite efforts to address poverty, more than a third of the world's population still live on less than $2 per day. This needs our immediate attention. Environment and development must go hand in hand. We need to:

• Achieve the Millennium Development Goals, in the spirit of the Millennium Declaration, recognising that global sustainability is a precondition of success.
• Adopt a global contract between industrialized and developing countries to scale up investment in approaches that integrate poverty reduction, climate stabilization, and ecosystem stewardship.

2. **Managing the climate - energy challenge:** We urge governments to agree on global emission reductions guided by science and embedded in ethics and justice. At the same time, the energy needs of the three billion people who lack access to reliable sources of energy need to be fulfilled. Global efforts need to:

• Keep global warming below 2°C, implying a peak in global CO_2 emissions no later than 2015 and recognise that even a warming of 2°C carries a very high risk of serious impacts and the need for major adaptation efforts.

• Put a sufficiently high price on carbon and deliver the G-20 commitment to phase out fossil fuel subsidies, using these funds to contribute to the several hundred billion US dollars per year needed to scale up investments in renewable energy.

3. **Creating an efficiency revolution** : We must transform the way we use energy and materials. In practice this means massive efforts to enhance energy efficiency and resource productivity, avoiding unintended secondary consequences. The "throw away concept" must give way to systematic efforts to develop circular material flows. We must:

• Introduce strict resource efficiency standards to enable a decoupling of economic growth from resource use.
• Develop new business models, based on radically improved energy and material efficiency.

4. **Ensuring affordable food for all**: Current food production systems are often unsustainable, inefficient and wasteful, and increasingly threatened by dwindling oil and phosphorus resources, financial speculation, and climate impacts. This is already causing widespread hunger and malnutrition today. We can no longer afford the massive loss of biodiversity and reduction in carbon sinks when ecosystems are converted into cropland. We need to:

• Foster a new agricultural revolution where more food is produced in a sustainable way on current agricultural land and within safe boundaries of water resources.
• Fund appropriate sustainable agricultural technology to deliver significant yield increases on small farms in developing countries.

5. **Moving beyond green growth :** There are compelling reasons to rethink the conventional model of economic development. Tinkering with the economic system that generated the global crises is not enough. Markets and entrepreneurship will be prime drivers of decision making and economic change, but must be complemented by policy frameworks that promote a new industrial metabolism and resource use. We should:

• Take account of natural capital, ecosystem services and social aspects of progress in all economic decisions and poverty reduction strategies. This requires the development of new welfare indicators that address the shortcomings of GDP as an indicator of growth.
• Reset economic incentives so that innovation is driven by wider societal interests and reaches the large proportion of the global population that is currently not benefitting from these innovations.

6. **Reducing human pressures**: Consumerism, inefficient resource use and inappropriate technologies are the primary drivers of humanity's growing impact on the planet. However, population growth also needs attention. We must:

• Raise public awareness about the impacts of unsustainable consumption and shift away from the prevailing culture of consumerism to sustainability.
• Greatly increase access to reproductive health services, education and credit, aiming at empowering women all over the world. Such measures are important in their own right but will also reduce birth rates.

7. **Strengthening Earth System Governance**: The multilateral system must be reformed to cope with the defining challenges of our time, namely transforming humanity's relationship with the planet and rebuilding trust between people and nations. Global governance must be strengthened to respect planetary boundaries and to support regional, national and local approaches. We should:

• Develop and strengthen institutions that can integrate the climate, biodiversity and development agendas.
• Explore new institutions that help to address the legitimate interests of future generations.

8. **Enacting a new contract between science and society:** Filling gaps in our knowledge and deepening our understanding is necessary to find solutions to the challenges of the Anthropocene, and calls for major investments in science. A dialogue with decision-makers and the general public is also an important part of a new contract between science and society. We need to:

• Launch a major initiative on the earth system research for global sustainability, at a scale similar to those devoted to areas such as space, defence and health, to tap all sources of ingenuity across disciplines and across the globe.
• Scale up our education efforts to increase scientific literacy especially among the young.

We are the first generation facing the evidence of global change. It therefore falls upon us to change our relationship with the planet, in order to tip the scales towards a sustainable world for future generations.

Sustainability Measures, Traditional vs. Sustainability Indicators, http://www.sustainablemeasures.com/node/90

Economic Indicators		
Traditional Indicators	**Sustainability Indicators**	**Emphasis of Sustainability Indicators**
Median income Per capita income relative to the U.S. average	Number of hours of paid employment at the average wage required to support basic needs	What wage can buy Defines basic needs in terms of sustainable consumption
Unemployment rate Number of companies Number of jobs	Diversity and vitality of local job base Number and variability in size of companies Number and variability of industry types Variability of skill levels required for jobs	Resilience of the job market Ability of the job market to be flexible in times of economic change
size of the economy as measured by GNP and GDP	Wages paid in the local economy that are spent in the local economy Dollars spent in the local economy which pay for local labor and local natural resources Percent of local economy based on renewable local resources	Local financial resilience
Environmental Indicators		
Traditional Indicators	**Sustainability Indicators**	**Emphasis of Sustainability Indicators**
Ambient levels of pollution in air and water	Use and generation of toxic materials (both in production and by end user) Vehicle miles traveled	Measuring activities causing pollution
Tons of solid waste generated	Percent of products produced which are durable, repairable, or readily recyclable or compostable	Conservative and cyclical use of materials
Cost of fuel	Total energy used from all sources Ratio of renewable energy used at renewable rate compared to nonrenewable energy	Use of resources at sustainable rate
Social Indicators		
Traditional Indicators	**Sustainability Indicators**	**Emphasis of Sustainability Indicators**
SAT and other standardized test scores	Number of students trained for jobs that are available in the local economy Number of students who go to college and come back to the community	Matching job skills and training to needs of the local economy
Number of registered voters	Number of voters who vote in elections Number of voters who attend town meetings	Participation in democratic process Ability to participate in the democratic process

APPENDIX G

Samples of sustainability-oriented indicators

1. **Ecological Footprint Indicator**

The Ecological Footprint (EF) measures how much of the regenerative capacity of the biosphere is used up by human activities (consumption). It does so by calculating the amount of biologically productive land and water area required to support a given population at its current level of consumption. The EF process studies land use based on six different types: crop land, forest land, fishing grounds, grazing land, carbon uptake land, built-up land. A country's Footprint (demand side) is the total area required to produce the food, fiber and timber that it consumes, absorb the waste that it generates, and provide space for its infrastructure (built-up areas). On the supply side, biocapacity is the productive capacity of the biosphere and its ability to provide a flux of biological resources and services useful to humankind. The EF once converted to a per capita basis, the EF can be used to compare how wasteful and inefficient one population is versus another. The strength in the EF indicator is that it is highly intuitive and easy to conceptualize. The indicator has been adapted to create water footprints, energy footprints, fiber footprints, poverty footprints, to name a few. The EF's shortcomings include the fact that it focuses exclusively on environmental variables and that it relies on large national datasets that are sometimes hard to source. The EF has not traditionally measured the impact on the oceans or does not take into account emissions released by the combustion of fossil fuels, beyond CO_2, or other contaminants like hazardous waste and heavy metals[137]. The EF indicator will continue to evolve with many modifications suggested including approaches based on the Second Law of Entropy (see below).[138]

2. **Emergy Accounting and Index of Sustainability**

H.T. Odum defined sustainability as "1) Every process must be environmentally sound (ecological compatibility), 2) every process must provide a suitable yield to society (economic compatibility)."[139] The Sustainable index he formulated measures the economic yield produced for per unit of environmental stress. Where environmental stress is represented by the Environmental Loading Ratio which is the nonrenewable flows of emergy from within the system added to the total emergy imported into the system divided by renewable flows of emergy from within the system. Where emergy is defined as the sum of all inputs of energy (directly and indirectly) required by a process to provide a product expressed in solar units. The economic yield produced is represented by Emergy Yield Ratio which is the ratio of emergy of output divided by imported emergy brought into the system. The objective is to obtain the highest yield ratio at the lowest environmental loading thereby minimizing exploitation of nonrenwables. Odum and others have applied the Index of Sustainability to man-made systems to track and compare the sustainability of nations and industries.[140,141,142] The analysis for industries is particularly helpful in determining misuse of environmental contributions when increases in input emergy are lower than yield increases.

3. **Osberg and Sharpe Index of Economic Well-Being**

This index is a composite indicator that covers prosperity (consumption measurements), sustainable accumulation and social topics (reduction in inequalities and protection against social risks). Environmental issues are measured by cost of CO2 emissions per capita). It counters the richness of dashboards and synthesizes information into a single number. Weakness is that it does not indicate at what threshold a country is not on a sustainable path.

4. **Environmental Sustainability Index**

The ESI uses 76 variables to cover five domains: environmental systems, environmental stress, human vulnerability, social and institutional capacity and global stewardship. It was created in the late 1990's by Yale and Colombia Universities and is actively promoted by the World Economic Forum.[143] On the minus side its calculation is complex with an input of 76 variables which are statistically massaged (adjusted for skewness for example). The indicator is normalized to a value between 0 and 100 which gives it power through its ease of interpretation and through its comparability. So the indicator is useful in attracting attention (name and shaming perhaps) but requires other tools and indicators to provide more information on what is happening on the ground.

5. Adjusted Net Savings

ANS represents Gross National Savings (Gross National Income less private and public consumption) and adds back investments in human capital while subtracting depletion of natural resources and damage caused by pollution. The indicator takes a broad view that natural and human capital are assets upon which the productivity and therefore well-being of a nation depend. Depletion and degradation of resources through pollution represent a disinvestment in future productivity and well-being. While an educated and skilled workforce acts as an investment in future productivity and wellbeing. The idea is that sustainability requires the maintenance of a constant stock of 'extended wealth' that will be available to pass onto future generations. Pearce and Atkinson formally introduced the concept in 1993 and Hamilton and Clemens provided a great deal of empirical evidence showing that levels of savings for many countries were actually negative when the environment and natural resources are poorly managed.[144] The World Bank tracks ANS annually and has 35-year time-series estimates through its World Development Indicators and its Little Green Data book datasets. A major shortcoming of ANS is its limited focus on measurement of carbon dioxide emissions as the only pollutant of importance. Environmental degradation from other pollutants not only on air quality but also on water bodies and on soil should also be considered. Likewise biodiversity loss should optimally also be measured, although pricing becomes a tricky issue. Computing ANS on a per country basis may be missing the point that sustainability is truly global in nature. There is also a risk of ANS under-reporting sustainability of resource exporting countries and over-reporting sustainability for resource importers.

6. Genuine Progress Indicator

GPI tries to measure improvement in quality of life starting with personal consumption and then adds or subtracts positive or negative contributions. GPI tries to rectify the fact that GDP only reports on how much income is produced but not how income is distributed. The first adjustment is the distribution of income to society. The Canadian Atlantic GPI measuring the well-being of the province of Nova Scotia has been tracking the indicator for over ten years and has produced more than 80 research reports helping evolve the GPI index approach. The components: 1) Time Use: Civic and voluntary work, unpaid household work and childcare, leisure time, paid work hours/employment, 2) Living Standards: Income distribution, financial security and debt, economic security, 3) Human and Social Capital: Population and health, safety and security, educated populace, 4) Natural Capital: Soils and agriculture, forests, fisheries and marine environment, air quality, water quality, 5) Human impact on the Environment: Energy, solid waste, ecological footprint, greenhouse gas emissions, transportation.

7. The Living Planet Index

The Living Planet index (LPI) reflects the changes in health of the planet's ecosystems by tracking trends in nearly 8,000 populations of vertebrate species. Much as a stock market index tracks the value of a set of shares over time as the sum of its daily change.

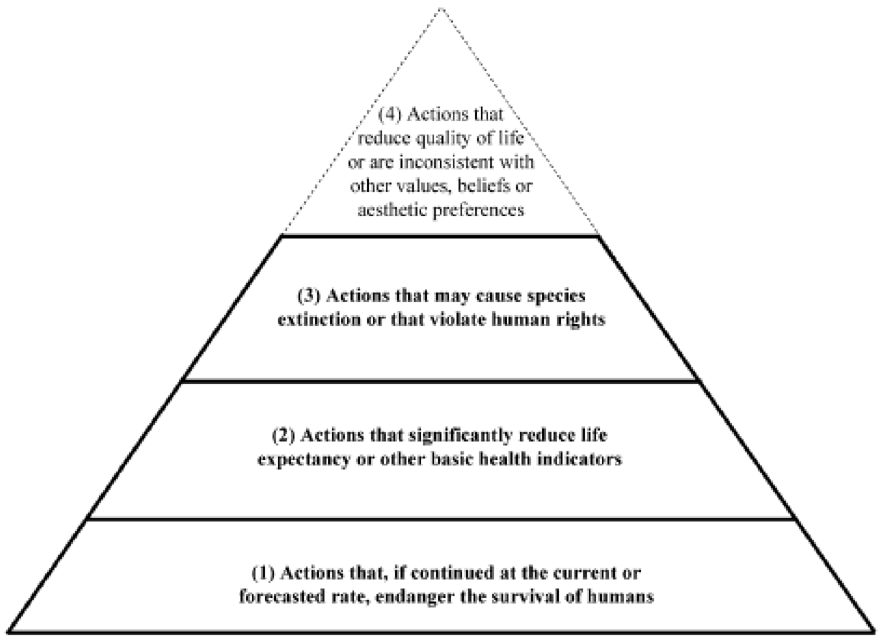
APPENDIX H

Sustainability as preservation of differing forms of capital. Source: Parkin S. et al, Sustainable development: understanding the concept and practical challenge. Proceedings of the Institute of Civil Engineers, March 2003.

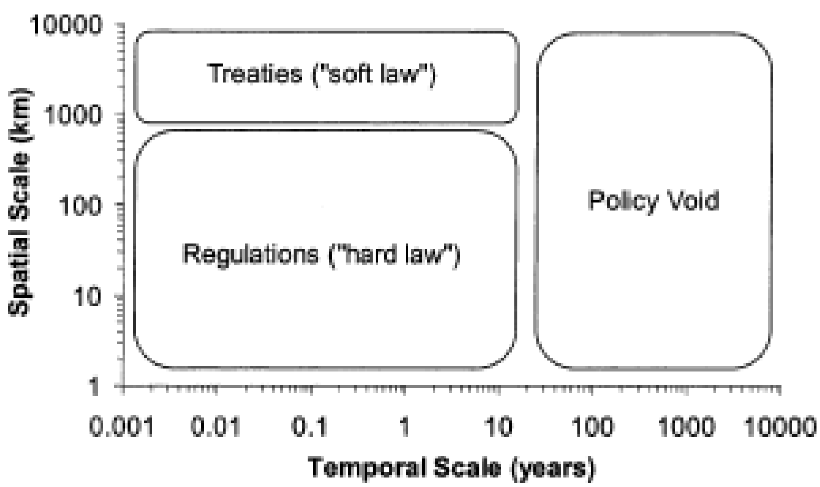
Natural capital	Also referred to as environmental or ecological capital and represents the stock of environmentally provided assets and falls into two categories. (a) Resources, some of which are renewable (trees, vegetation, fish, water), some nonrenewable (fossil fuels, minerals). In some places ostensibly renewable resources (such as fertile soil) have become non-renewable (desert). (b) Services, such as climate regulation or the powerful waste processing cycles.
Human capital	Consists of the health, knowledge, skills, motivation and spiritual ease of people. All the things that enable people to feel good about themselves, each other, and to participate in society and contribute productively towards its well-being (wealth). Recently recognized as providing a high return on investment, especially in developing societies (where investment in human resources is viewed as possibly the most essential ingredient of development strategies) but also in the highly industrialized world.
Social capital	Is all the different cooperative systems and organizational frameworks people use to live and work together, such as families, communities, governments, businesses, schools, trade unions, voluntary groups. Although they involve different types of relationships and organizations they are all structures or institutions that add value to human capital. Again, the importance of social capital has only recently been recognized; unfortunately however, there are increasingly visible negative effects when it is eroded.
Manufactured capital	Comprises all of the human fabricated 'infrastructure' that is already in existence: the tools, machines, roads, buildings in which we live and work, and so on. It does not include the goods and services that are produced, and in some cases manufactured capital may be viewed as a source of materials (e.g. building waste used as aggregate for road building or repair).
Financial capital	Has, strictly speaking, no intrinsic value; whether in shares, bonds or banknotes, its value is purely representative of natural, human, social or manufactured capital. Financial capital is nevertheless very important, as it reflects the productive power of the other types of capital, and enables them to be owned or traded.

APPENDIX I

Sustainability hierarchy with the most basic sustainability needs at the bottom. This hierarchy incorporates ways in which the term 'sustainability' is currently being used by scholars, policy-makers, companies and NGOs. Level 4 is important but should not be considered within the rubic of sustainability. Source: Marshall, J.D. and Toeffel, M.W., Framing the Elusive Concept of Sustainability: A sustainability Hierarchy, Environmental Science and Technology, Vol 39, No. 3, 2005

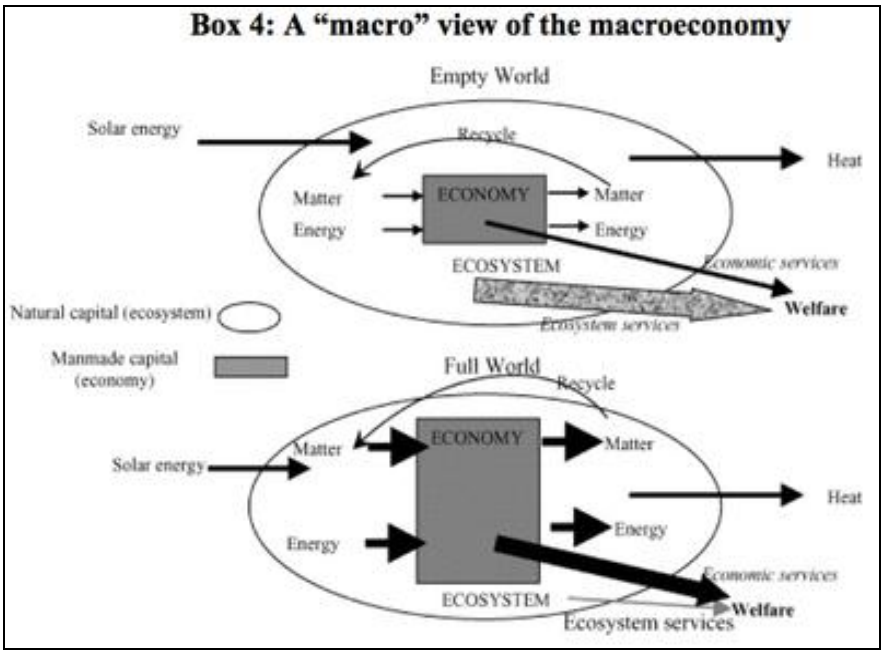


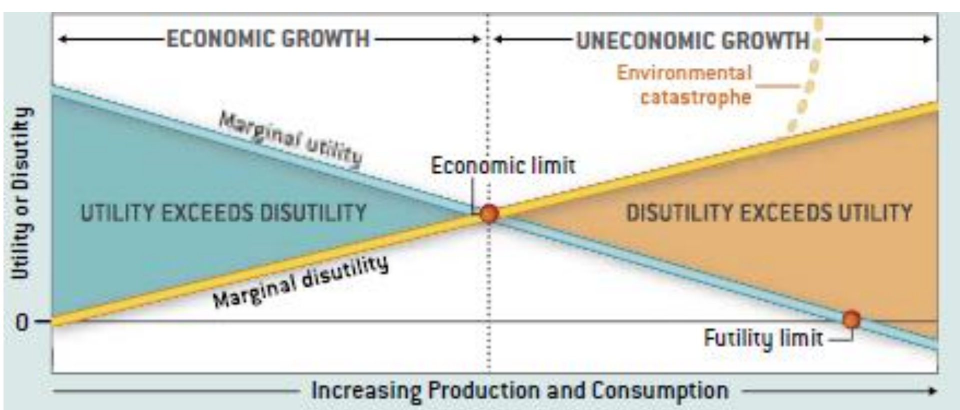
Temporal and spatial scales of environmental policies. There is often a policy void for sustainable issues in part because of the large temporal and spatial scales. Source as above.



APPENDIX J

The concept of an empty versus full world and the economy as an open subsystem of the ecosystem. Since the ecosystem remains constant in scale as the economy grows, it is inevitable that over time the economy becomes larger relative to the containing ecosystem. This transition from an 'empty world' to a 'full world' is depicted above. The point is that the evolution of the human economy has passed from an era in which man-made capital was the limiting factor in economic (Source Ecological Economics by Daly and F...) and the concept of the intersection of marginal utility and disutility as the economic limit (Source: Economics in a Full World, Herman E. Daly, Scientific American, September 2005). Daly's vision of the future outlined below (same source).





Daly's vision of a sustainable economy

"What is involved in establishing and maintaining a sustainable economy:

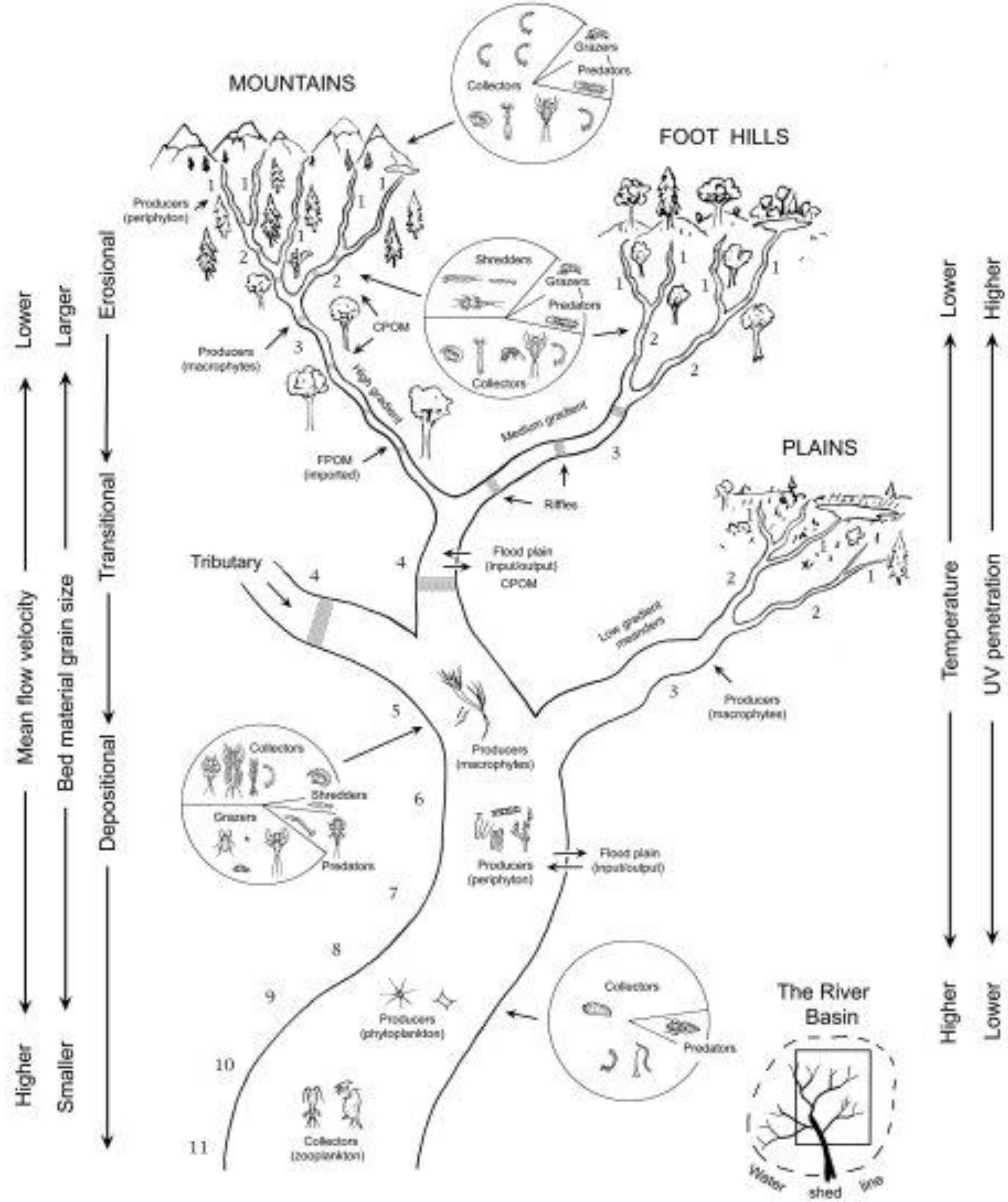
- The sustainable economy must at some point stop growing, but it need not stop developing. There is no reason to limit the qualitative improvement in design of products, which can increase GDP without increasing the amount of resources used. The main idea behind sustainability is to shift the path of progress from growth, which is not sustainable, toward development, which presumably is.
- Economic theory has traditionally dealt mainly with allocation (the apportionment of scarce resources among competing uses). It has not dealt with the issue of scale (the physical size of the economy relative to the

ecosystem). Properly functioning markets allocate resources efficiently, but they cannot determine the sustainable scale; that can be achieved only by government policy.

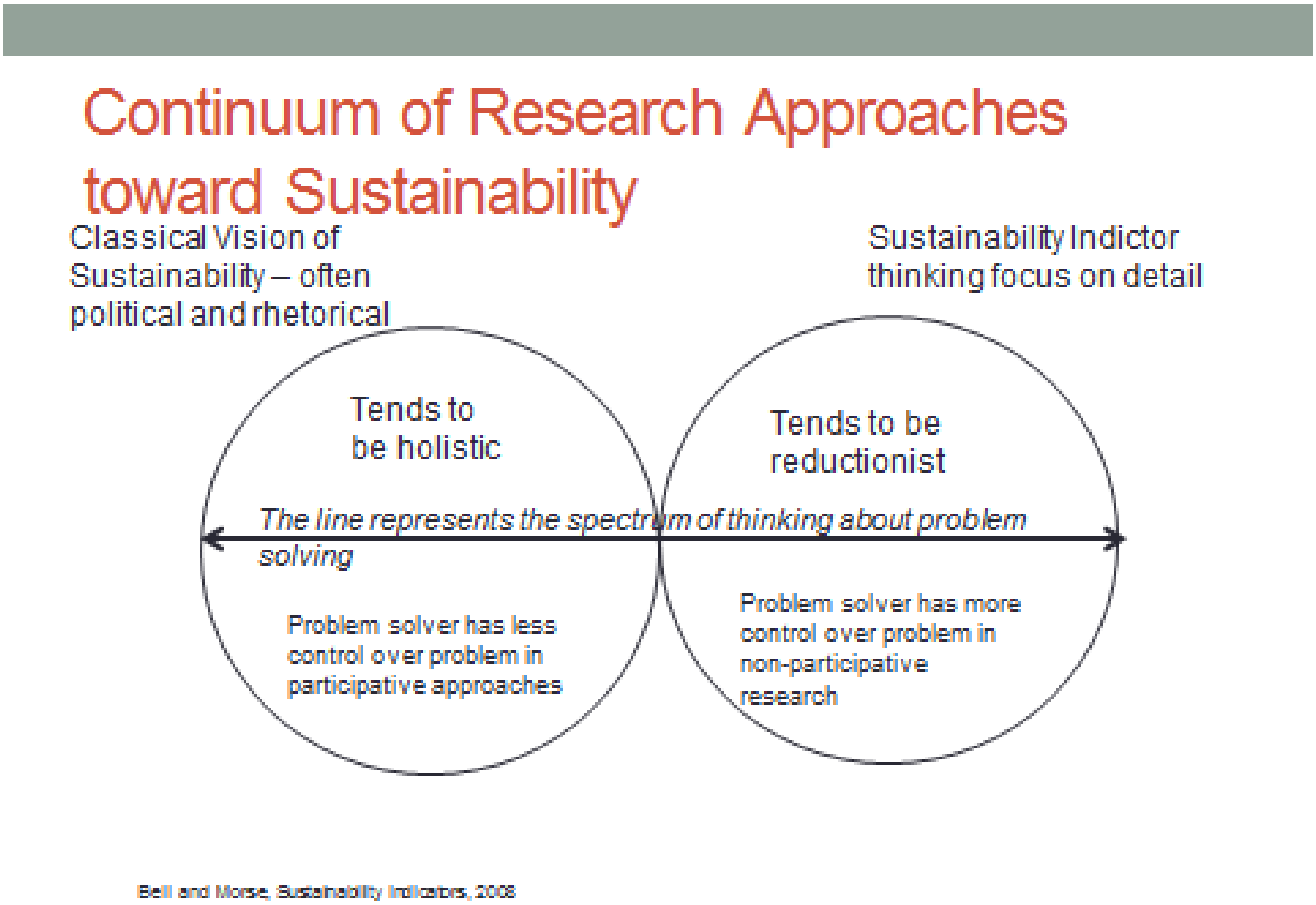
- A sustainable economy would require many adjustments to economic policy. Some such changes are already apparent. The U.S. Social Security system, for example, faces difficulties because the demographic transition to a non-growing population is leading to a smaller number of working age people and a larger number of retirees. Adjustment requires higher taxes, an older retirement age or reduced pensions. Despite assertions to the contrary, the system is hardly in crisis. But one or more of those adjustments are surely needed for the system to maintain itself.
- A sustainable economy requires a "demographic transition" not only of people but of goods—production rates should equal depreciation rates. The rates can be equal, however, at either high or low levels, and lower rates are better both for the sake of greater durability of goods and for attaining sustainability.
- In a sustainable economy the financial sector would shrink because low interest and growth rates could not support the enormous superstructure of financial transactions based largely on debt and expectations of economic growth. A sustainable economy, investment would be mainly for replacement and qualitative improvement, instead of for speculation on quantitative expansion, and would occur less often.
- Regulated trade under rules that compensated for differences between sustainability practices of countries could exist, as could free trade among nations that were equally committed to sustainability.
- Taxing what we want less of (resource depletion and pollution) and ceasing to tax what we want more of (income) would seem reasonable. The regressivity of such a consumption tax (the poor would pay a higher percentage of their income than the wealthy would) could be offset by spending the proceeds progressively (that is, focused on aiding the poor), by instituting a tax on luxury items or by retaining a tax on high incomes.
- In a sustainable economy, maintenance and repair become more important. Being more labor-intensive than new production and relatively protected from offshoring, these services may provide more employment. Yet a more radical rethinking of how people earn income may be required. If automation and offshoring of jobs results in more of the total product accruing to capital (that is, the businesses and business owners profit from the product), and consequently less to the workers, then the principle of distributing income through jobs becomes less tenable. A practical substitute may be to have wider participation in the ownership of businesses, so that individuals earn income through their share of the business instead of through full-time employment."

APPENDIX K

RIVER CONTINUUM CONCEPT
The RCC of a river which reflects the changes in abiotic structure and the biotic community composition of a river as it moves from upstream to downstream. Source Vannote 1990.

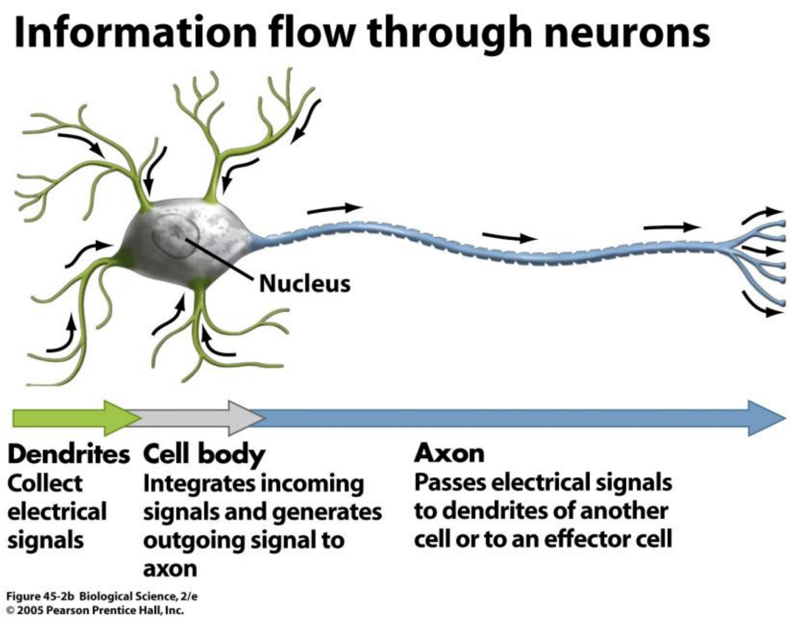


APPENDIX L

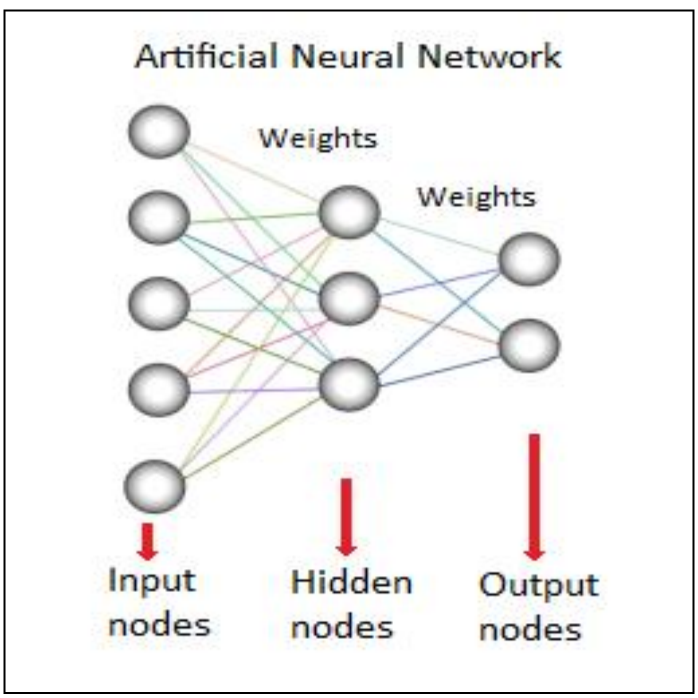

Continuum of Research Approaches toward Sustainability
Classical Vision of Sustainability – often political and rhetorical
Sustainability Indictor thinking focus on detail
Tends to be holistic
Tends to be reductionist
The line represents the spectrum of thinking about problem solving
Problem solver has less control over problem in participative approaches
Problem solver has more control over problem in non-participative research
Bell and Morse, Sustainability Indicators, 2008

APPENDIX M

Artificial Neural Network Design
Structure of a nerve cell. Dendrites receive signals, signal is aggregated and then impulse is sent to terminal branches. A Neural Network approach to decision making mimics this biological model.

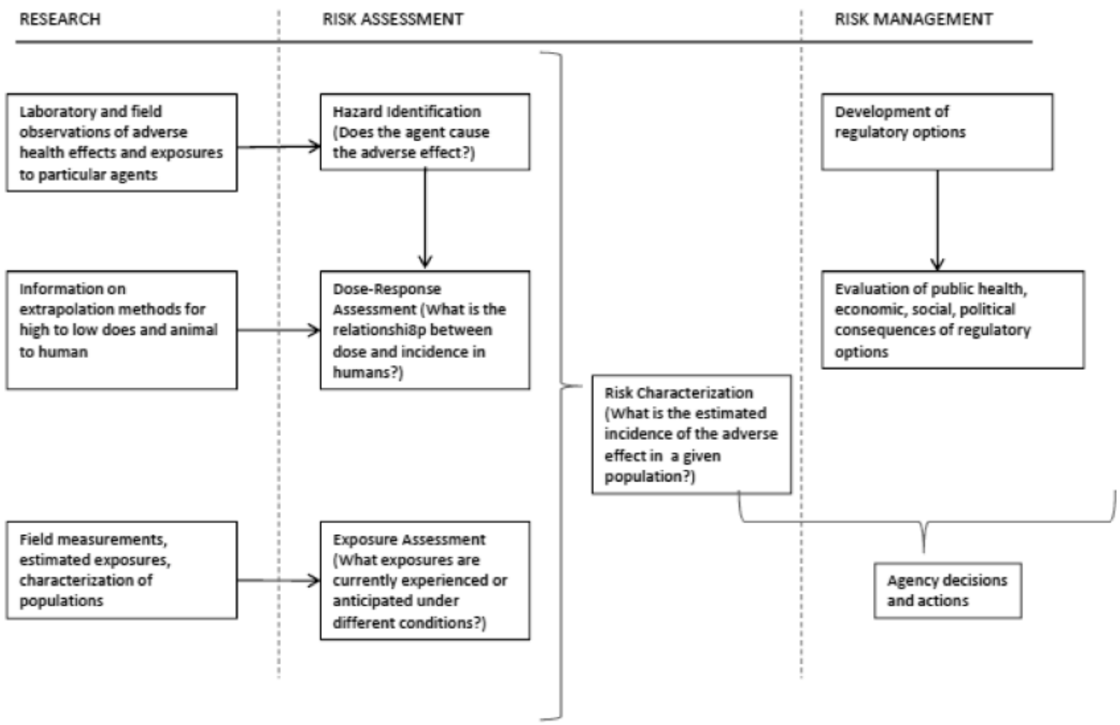


Artificial Neural Network based on layers with inputs and hidden nodes carrying various weights and interactions and output nodes having threshold values. Source for photo: website of Dr. Sayed

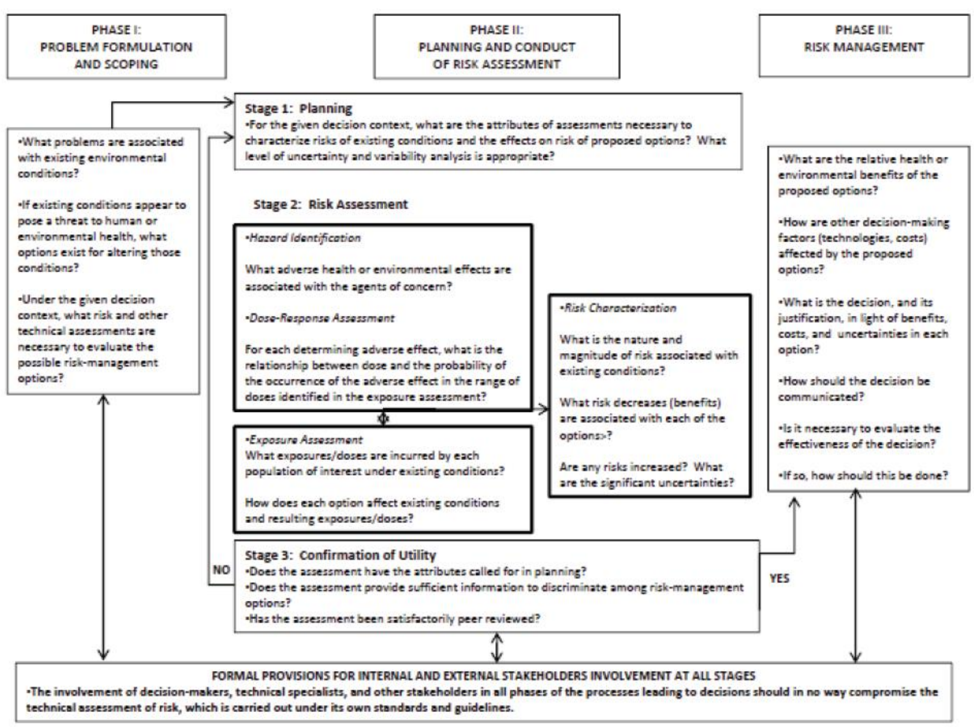


APPENDIX N

Elements of risk assessment and risk management in the National Research Council's Red Book guiding all federal agencies produced in 1983.



The 2009 Version reflecting higher complexities



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The Human Wellbeing Index (HWI) is the lower of the HWI including equity (HWI + equity) and the HWI excluding equity (HWI - equity). The former is the unweighted average of indices of health and population, wealth, knowledge, community, and equity. The latter is the unweighted average of indices of health and population, wealth, knowledge, and community. Taking the lower version of the HWI prevents equity from offsetting poor performance in the other human dimensions.

The Ecosystem Wellbeing Index (EWI) is the lower of the EWI including resource use (EWI + RU) and the EWI excluding resource use (EWI - RU). The former is the unweighted average of indices of land, water, air, species and genes, and resource use. The latter is the unweighted average of indices of land, water, air, and species and genes. Taking the lower version of the EWI prevents resource use (a set of indicators of human pressure on the ecosystem) from offsetting poor performance in the other ecosystem dimensions (primarily sets of indicators of the state of the ecosystem).
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